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Forecasting and combining competing models of exchange rate determination

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FORECASTING AND COMBINING COMPETING MODELS OF EXCHANGE RATE DETERMINATION

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FORECASTING AND COMBINING COMPETING MODELS OF EXCHANGE RATE DETERMINATION

Abstract

This paper investigates the out-of-sample forecast performance of a set of competing models of exchange rate determination. We compare standard linear models with models that characterize the relationship between exchange rate and its underlying fundamentals by nonlinear dynamics. Linear models tend to outperform at short forecast horizons especially when deviations from long-term equilibrium are small. In contrast, nonlinear models with more elaborate mean-reverting components dominate at longer horizons especially when deviations from long-term equilibrium are large. The results also suggest that combining different forecasting procedures generally produces more accurate forecasts than can be attained from a single model.

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Keywords: non-linearity, exchange rate modelling, forecasting.

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1. Introduction

There is an ongoing debate about exchange rate predictability in time series data. A large body of empirical literature, reviewed by Frankel and Rose (1995) and Meese (1990), focuses on whether existing theoretical and econometric models of exchange rate determination represent good descriptions of the empirical data.

Nevertheless, the literature has not converged on a particular class of models capable of challenging the Meese and Rogoff (1983) result that structural macro-models cannot out-perform a naïve random-walk. Most of the studies conclude that monetary fundamentals such as the GDP differential, the inflation differential, the relative money growth, and the short-term interest rate differential have negligible out-of-sample predictive power at least over short time horizons. However, there is some evidence that with longer time horizons the forecasting accuracy of fundamentals based exchange rate models improves (see e.g. Mark (1995) and Cheung et al. (2003))[1].

Some authors have stressed that the poor forecasting performance of fundamental-based models is not related to the weak informative power of fundamentals. The superiority of random-walk forecasts is instead related to the weakness of the econometric techniques used in producing out-of-sample forecasts (see Taylor and Peel(2000). In a recent study, Sarno and Valente (2005) analyse how to optimally select the correct number of fundamentals to be used in computing the best forecasting model in each period. They show that *ex-ante* it is not possible to implement a procedure that is able to account for the frequent shifts occurring in the weight each fundamental has in driving exchange rate dynamics.

Recently, an important empirical literature has emerged showing strong empirical evidence that the dynamics governing the exchange rate behaviour may be nonlinear (Taylor and Peel(2000), Sarno, Taylor and Peel(2000)). In this line of research, Altavilla and De Grauwe (2005), show that the exchange rate process can be modelled by a nonlinear error-correction model where deviations from the long-run equilibrium are mean-reverting but occasionally follow a nonstationary process. Nonlinearity leads to the inadequacy of the usual assumption made in the theoretical and empirical

[1] But see the criticism of Faust and Rogers (2003).

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literature that the dynamic adjustment of the exchange rate towards its long-run steady state is linear.

The literature on exchange rate determination[2] has produced mixed evidence on the out-of-sample predictive power of nonlinear models[3]. More precisely, the superiority of the Markov-switching forecast with respect to the random walk, firstly stressed by Engel and Hamilton (1990), has recently been emphasized by Clarida et al. (2003).

However, while these models are found to produce an accurate representation of the in-sample exchange rate movements, they fail to consistently beat naïve random walk models in out-of-sample forecasting[4]. It is then natural to produce comparative exercises on the forecasting ability of the nonlinear versus linear models of exchange rate determination.

The present study contributes to the ongoing debate regarding the possibility of correctly forecasting future exchange rate movements. The econometric evidence resulting from this kind of study can suggest which model should be adopted in order to achieve a better forecasting performance. A common characteristic of much of the existing studies is their focus on either linear or non-linear models. After this preliminary choice, selected models are then compared with a random walk process. The contribution of the paper with respect to the existing literature is twofold.

First, we estimate a set of competing models including both linear and non-linear ones and show that the forecasting performance of competing models varies significantly across currencies, across forecast horizons and across sub-samples.

Second, we show that combining competing models of exchange rate forecasting, reflecting the relative ability each model has over different sub-samples, leads to more accurate forecasts.

The remainder of the paper proceeds as follows. Section 2 presents a set of competing model of exchange rate determination. Section 3 compares out-of-sample

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[2] See Sarno and Taylor(2002) for a comprehensive discussion of competing models of exchange rate determination.

[3] See Engel (1994) on the use of Markov switching models for forecasting short-term exchange rate movements. More recently, Kilian and Taylor (2003) find some evidence on exchange rate predictability at horizon of 2 to 3 years by using ESTAR modelling. However, the power of the results decreases when the horizon is shorter.

[4] See Diebold and Nason, 1990; Engel, 1994; Meese and Rose, 1990, 1991.

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point forecasts of the estimated models. Section 4 performs a quantitative exercise of forecast estimation and evaluation strategy. In particular, the study considers three classes of statistical measures - point forecast evaluation, forecast encompassing and directional accuracy. In Section 5, concluding remarks end the paper.

2. Selecting and Estimating Competing Models

Our empirical analysis focuses on the forecasting properties over horizons from 1 quarter to 8 quarters of seven competing models which we, now, describe in detail. These models are used to compute out-of-sample forecasts of three US dollar exchange rates: the dollar-euro, the dollar-sterling and the dollar-yen. All data used in the analysis are quarterly and were drawn from Datastream. The sample period goes from 1970:1 to 2005:3.

The *first model* consists of a driftless random walk process (RW). This framework remains a useful benchmark against which exchange rate models are judged. The dynamics of the model is as follows:

[1] $$e_t = e_{t-1} + \varepsilon_t$$

where e_t represents the nominal exchange rate.

The *second model* uses spectral analysis (SP). In general, exchange rate behaviour is expressed as a function of time. This representation may not necessarily be the most informative. In order to better analyse exchange rates evolution we combine a time domain approach with a frequency domain approach. In particular, spectral analysis might be useful in detecting regular cyclical patterns, or periodicities, in transformed exchange rate data. Significant information may be hidden in the frequency domain of the time series. Frequency-domain representations obtained through an appropriate transformation of the time series enable us to access this information.

In order to map the exchange rate from the time domain into the frequency domain we apply the Fourier transformation. Starting from the time series $\left\{\Delta e(t)\right\}_1^T$ this transformation is based on the following equation:

[2] $$\Delta e(2\pi j/T) = \sum_{t=1}^{T} \Delta e(t)\exp\left(-2\pi ij(t-1)/T\right)$$

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where the frequencies range from zero to $\left(2\pi\left(t-1\right)/T\right)$ by increments of $2\pi/T$. Having transformed the series, we can look at the correlation between $\Delta e\left(t\right)$ and complex exponential (sine and cosine) functions of different frequencies. If a substantial proportion of the variance in $\Delta e\left(t\right)$ is due to cycles of frequency $\left(2\pi\, j/T\right)$, then $\Delta e\left(2\pi j/T\right)$ will be relatively large.

Starting from the moving average representation of the selected time series we follow the procedure outlined in Koopmans (1974) to compute out-of sample forecasts using spectral techniques.

The *third model* is a four-variable vector error correction model (VECM):

[3]
$$\Delta x_t = c + \sum_{i=1}^{k-1} \Gamma_i \Delta x_{t-i} + \Pi x_{t-k} + \varepsilon_t$$

$$x_t = \left[y_t \;\; \pi_t \;\; i_t \;\; e_t \right]'$$

In the above model, y_t is the GDP differential, measured as the difference between the USA and the foreign country's real GDP; π_t represents the inflation rate differential[5]; i_t is the short-term interest rate differential, and e_t is the nominal exchange rate.

This model takes into account the cointegration properties of the integrated variables. More precisely, as the above variables are nonstationary in levels but stationary in first differences we can consistently estimate the model by applying the first difference operator to each variable. However, filtering the selected variables may produce a misinterpretation of the long-run relationship among the non-stationary variables.

The *fourth model* is a smooth transition autoregressive model (STAR). The general form of the STAR[6] model is as follows:

[4]
$$e_t = \phi_{10} + \phi_1^{'} \varpi_t + \left(\phi_{20} + \phi_2^{'} \varpi_t\right) \Gamma\left(e_{t-d}; \gamma, \mu\right) + \varepsilon_t$$

[5] The inflation rate in each country is calculated as the percentage change in the annual CPI inflation rate, i.e. $100\left(\log CPI_t - \log CPI_{t-4}\right)$.

[6] Note that the ESTAR model can be viewed as a generalization of the double-threshold TAR model.

where $\{e_t\}$ is a stationary and ergodic process, $\varpi_t = \left(e_{t-1},........,e_{t-p}\right)$ a vector of lagged values, $\varepsilon_t \sim iid(0,\ \sigma^2)$. The transition function $\Gamma\left(e_{t-d};\gamma,\mu\right)$ depends on a transition variable (e_{t-d}), the speed of adjustment parameter $\gamma > 0$, and the equilibrium parameter *c*. In general, the transition function may have two different forms:

[5] $$\Gamma_1\left(e_{t-d};\gamma,\mu\right) = \left\{1+\exp\left[-\gamma\left(e_{t-d}-\mu\right)\right]\right\}^{-1}$$

[6] $$\Gamma_2\left(e_{t-d};\gamma,\mu\right) = 1-\exp\left[-\gamma\left(e_{t-d}-\mu\right)^2\right]$$

where the first equation describes a logistic function (LSTAR) and the second one represents an exponential function (ESTAR). The specific form of the transition function is usually tested by employing a battery of tests proposed by Granger and Teräsvirta (1993). However, in our case we directly estimate the model in its ESTAR form. In fact, the ESTAR model is more suitable than the LSTAR framework in analyzing the dynamic behaviour of the exchange rate deviations from equilibrium. This is so because the symmetry of the exponential transition function Γ_2 around μ implies a symmetric behaviour of the exchange rate adjustment regardless of whether the deviation form equilibrium is positive or negative. This means that the class of model used in the present study is:

[7] $$\Delta e_t = \mu + \sum_{i=1}^{p}\alpha_i\left(\Delta e_{t-i}-\mu\right) + \left\{1-\exp\left[-\gamma\left(e_{t-d}-\mu\right)^2\right]\right\}\sum_{i=1}^{p}\alpha_i^*\left(\Delta e_{t-i}-\mu\right)+\varepsilon_t$$

This transition function has a minimum of zero at $e_{t-d} = \mu$ and approaches unity as $e_{t-d} - \mu \rightarrow \pm\infty$. As a consequence, the ESTAR model is in the first regime when e_{t-d} is close to μ and in the second regime when deviations of e_{t-d} from its equilibrium value (in both direction) are large. Within each regime, the exchange rate reverts to a linear autoregressive representation, with different parameter values and asymmetric speeds of adjustment.

The specific form used in the analysis is:

[8] $$\Delta e_t = \mu + \left(\Delta e_{t-1}-\mu\right) + \left\{1-\exp\left[-\gamma\left(e_{t-1}-\mu\right)^2\right]\right\}\sum_{i=1}^{4}\alpha_i^*\left(\Delta e_{t-i}-\mu\right)+\varepsilon_t$$

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The *fifth model* is a univariate Markov-switching model (MS-AR) similar to the one estimated by Engel and Hamiltom (1990). In this model, the dynamics of discrete shifts follows a two-state Markov process with an *AR(4)* component. The lag structure has been tested with standard AIC, HQ and SC criteria. These statistics suggest an autoregressive structure of order four. The model has the form:

[9] $$\Delta e_t - \mu(s_t) = \sum_{i=1}^{4} \alpha_i \left(\Delta e_{t-i} - \mu(s_{t-i})\right) + \varepsilon_t$$

where $\varepsilon_t \sim NID(0,\ \sigma^2)$ and the conditional mean $\mu(s_t)$ switches between two states:

$$\mu(s_t) = \begin{cases} \mu_1 > 0 \text{ if } s_t = 1 \\ \mu_1 < 0 \text{ if } s_t = 2 \end{cases}$$

s_t is a generic ergodic Markov chain defined by the transition probabilities: $p_{ij} = \Pr\left(s_{t+1} = j \mid s_t = i\right)$, $\sum_{i=1}^{M} p_{ij} = 1 \ \ \forall i,\ \ j \in \{1,\ 2\}$. The transition probabilities express the probability of moving from one state to another. Our hypothesis is that the above process follows a two-state Markov chain. It is then possible to express the transition probabilities in a 2×2 transition matrix: $P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix}$, where p_{ij} represents the probability of moving from state i to state *j*. In other words, p_{12} is the fraction of the times that the system in state 1 moves to state 2. Estimating a Markov-switching model involves an estimation of all the parameters and the hidden Markov chain followed by the regimes. Maximum likelihood estimates of the model can be recovered by performing a numerical maximization technique as described in Berndt et al.(1974).

The *sixth model* consists of a Markov switching VECM (MS-VECM). As in the linear case, it is made up of four variables (*y*, π, *i* and *e*). Following the two-stage procedure suggested by Krolzig (1997) the results obtained in the linear VECM concerning the cointegration analysis are used in this stage of the analysis.

The hypothesis behind the specific form of the estimated model is that the dynamics of the exchange rate process follows a 3-state Markov chain. The idea is that

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the relation between the exchange rate and the fundamentals is time-varying but constant conditional on the stochastic and unobservable regime variable. More specifically, the model allows for an unrestricted shift in the intercept and the variance-covariance matrix and for two lags in each variable [7]:

$$\Delta x_t = c(s_t) + \sum_{i=1}^{k-1} \Gamma_i \Delta x_{t-i} + \alpha\beta' x_{t-k} + \varepsilon_t \tag{10}$$

$$x_t = \left[y_t \;\; \pi_t \;\; i_t \;\; e_t \right]'$$

where the residuals are conditionally Gaussian, $\varepsilon_t \big| s_t \sim NID\left(0, \Sigma\left(s_t\right)\right)$.

The *seventh model* accounts for the time varying forecast ability of alternative models. The idea behind combining forecasting techniques is straightforward: no forecasting method is appropriate for all situations. This means that single forecasting models may be optimal only conditional on a given sample realization, information set, model specification or time periods. By implementing a combination of methods, we can compensate the weakness of a forecasting model under particular conditions.

Altough the theoretical literature[8] suggests that appropriate combinations of individual forecasts often have superior performance, such methods have not been widely exploited in the empirical exchange rate literature (see the recent study of Sarno and Valente (2005) however).. In the present study we compute combined forecasts using the methodology proposed in Hong and Lee (2003), Yang (2004) and Yang and Zou (2004).

Denoting e_t^k the exchange rate forecast series obtained from model *k*, where *k=1,…,6* represents the six models outlined above (i.e. RW, SP, MS-AR, VECM, MS-VECM, ESTAR) the combined forecast is obtained as:

$$e_t^{k*} = \sum_{i=1}^{6} \omega_{kt} e_t^k \tag{11}$$

[7] We also estimated the model allowing for a shift in the mean of the variables. The results we obtained from the two specifications are very similar with respect to the regime classification as well as to the parameter values. As we expected, the differences between the two models mainly consist of the different pattern of the dynamic propagation of a permanent shift in regime. More precisely, in the MSIH model, the expected growth of the variables responds to a transition from one state to another in a smoother way. See Krolzig (1997) on the peculiarity of the two models.

[8] See for example Bates and Granger (1969), Granger and Ramanathan (1984) and Clemen (1989).

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where the weights (ω_{kt}) attached to each model are calculated as follows:

[12]
$$\omega_{kt} = \frac{\exp\left[-\frac{1}{2}\sum_{j=1}^{t-1}\frac{\left(e_j - e_j^k\right)^2}{\sigma_t^2}\right]}{\sum_{k=1}^{6}\exp\left[-\frac{1}{2}\sum_{j=1}^{t-1}\frac{\left(e_j - e_j^k\right)^2}{\sigma_t^2}\right]}$$

where σ_t^2 is the actual conditional variance of the exchange rate.

The specific relationship imposed ensures that a weight attributed to a certain model at time *t* is larger the larger has been its ability to forecast the actual exchange rate in period *t-1*. Figure 1 shows the weights used in computing the combined forecast series.

Visual inspection provides useful information concerning the time-varying forecast abilities of competing models. A situation where the weights attributed to each model are very similar, as in the central part of the sample period for the 1-quarter-ahead forecast of the pound, suggests that the relative accuracy of the forecasts produced by each model may not be affected by a particular sub-sample period selected by the evaluation strategy. Moreover, the results obtained with one model are not different from the others. When, instead, weights are very dissimilar, a correct choice of the forecasting model may produce a significant improvement in terms of predictive accuracy.

The figure also suggests that there is a positive relationship between the volatility of the selected weights, i.e. the number of time each model account for the same proportion in the combing series, and the forecasting horizon.

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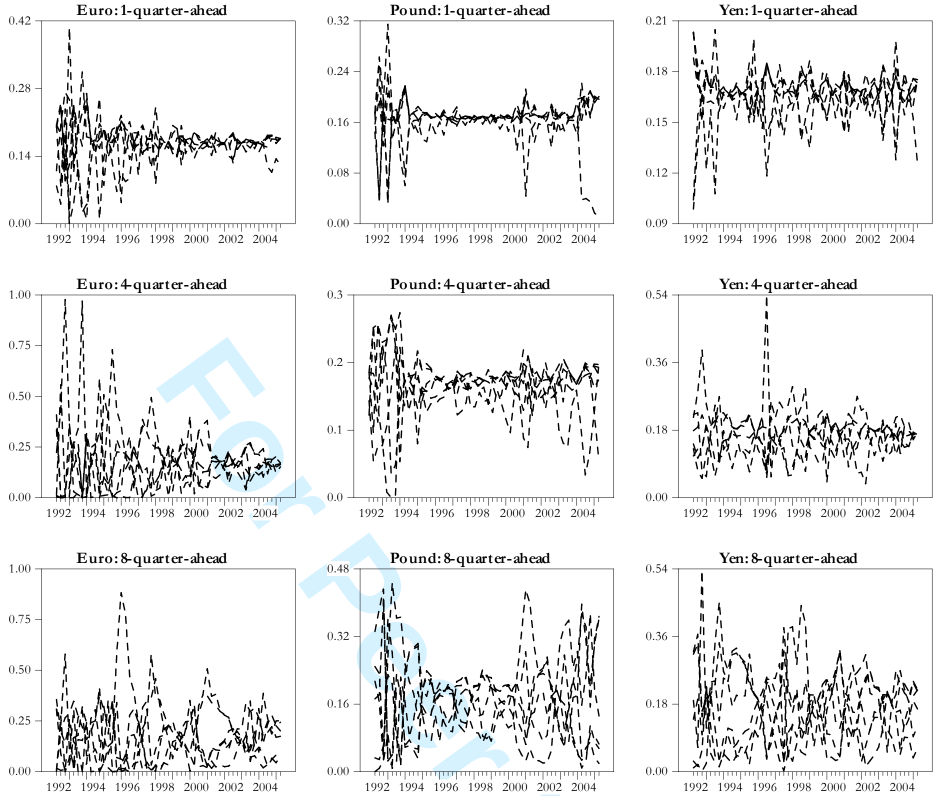
Figure 1: Weights used in Combining Forecasts



3. Comparing out-of-sample forecasts

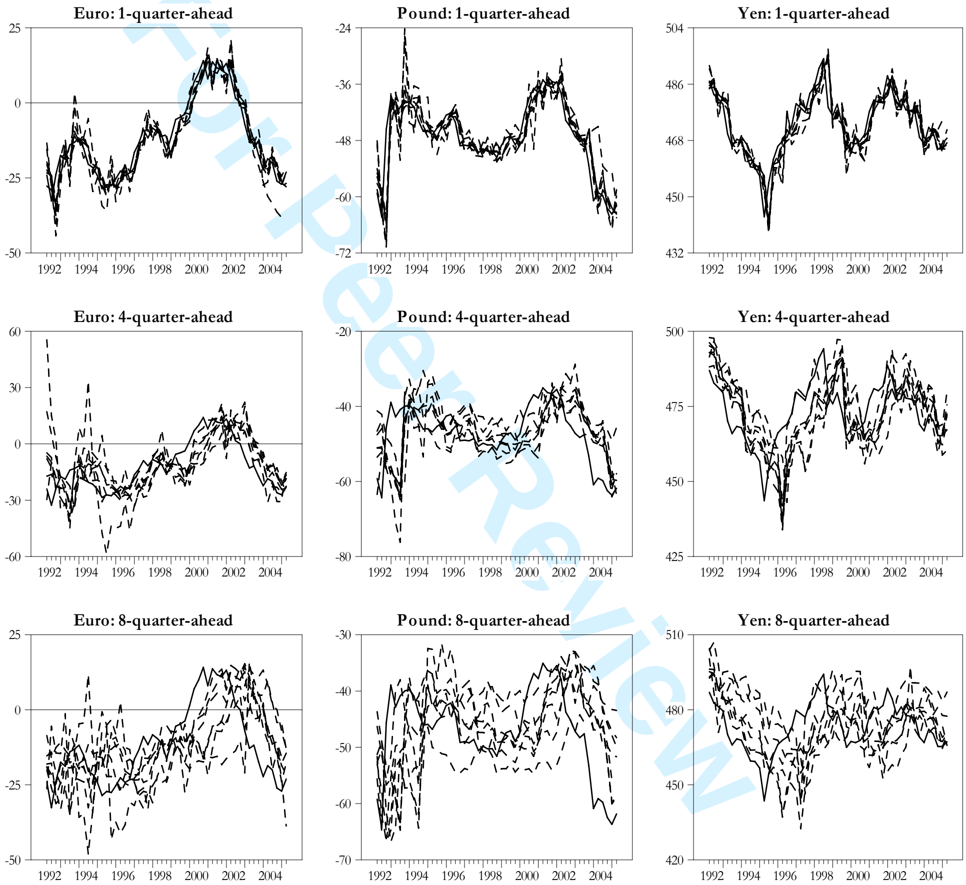
The seven models proposed above are estimated on a sub-sample of the historical data. Then the out-of sample forecasts of the competing models for alternative periods are evaluated. The forecast accuracy is measured by computing rolling forecasts. The estimation period goes from 1970:1 to 1989:4, while the forecast period goes from 1990:1 to 2005:3. This means that the first sequence of 1 to 8-quarter ahead forecast is generated starting from 1990:1. Then, the starting date of the forecast period is rolled forward one period, and another sequence of forecasts is generated. This loop is repeated until we have 62×1-quarter forecasts, down to 54×8-quarter forecasts.

Figure 2 provides a graphical summary of the performances of the competing models over the entire sample period in forecasting the three exchange rates. This figure illustrates the actual exchange rates (solid line) and the seven forecasting models (dashed lines) at 1-, -4 and 8-quarter-ahead horizon.

Visual inspection suggests a better performance, in terms of forecast errors, of short-horizon exchange rates forecasts. However, the figure also illustrates higher long-horizon forecast volatility. This means that the gains (but also the losses) we can achieve by using a particular model are larger the longer is the forecasting horizon.

However, in order to assess the performance of the alternative models we have to analyse the forecast accuracy through a set of statistical measures.

Figure 2: Out-of-sample Point Forecasts of competing models



4. Measuring forecast accuracy

The aim of this section is to examine the out-of-sample forecasting performance of alternative exchange rates models. Once each model has been estimated, the question arises as to how their performance may best be compared. In principle, forecast accuracy of competing models may be evaluated by employing various econometric procedures. Starting from the out-of-sample prediction errors, this paper

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computes three statistical measures – point forecasts, forecast encompassing tests and directional accuracy tests.

4.1 Point Forecasts Evaluation

We first use standard quantitative procedures involving forecast errors. The forecast error can be defined as: $e_{t+k} = x_{t+k} - \widehat{x}_{t+k}$, where $k \geq 1$ and $\widehat{x}_{t+h}$ represents the k-step-ahead forecast. The most widely used measure of forecast accuracy is the Root Mean Square Error (RMSE) . We can calculate it as follows:

$$RMSE = \left(\frac{1}{n} \sum_{i=1}^{n} e_{t+k+i}^{2} \right)^{1/2} \quad [13]$$

The comparison of forecasting performance based on this measure is summarized in Tables 1 and 2.

Each table characterizes some periods of the three exchange rates histories. Table 1 analyses the periods 1992-2005 and 1991-1998. The four periods described in table 2 are 1992-1995, 1995-1998, 1998-2001, and 2001-2005.

These tables also illustrate the relative ranking in terms of forecast errors for the 126 cases (seven models, three horizons, six sub-samples). The last column in each table reports the average ranks of the model over the three exchange rates.

Table 1: Comparing Forecast Accuracy

Panel A: 1992:1-2005:2

	Euro	*Rank*	Pound	*Rank*	Yen	*Rank*	*Avg. Rank*
1-quarter							
RW	4.16	*[1]*	3.66	*[3]*	5.10	*[4]*	[2.7]
SP	4.40	*[4]*	3.66	*[2]*	5.09	*[3]*	[3.0]
MS(2)-AR(4)	5.76	*[5]*	5.29	*[6]*	6.05	*[6]*	[5.7]
MS(3)-VEC(4)	6.54	*[7]*	5.82	*[7]*	6.43	*[7]*	[7.0]
ESTAR	4.28	*[3]*	3.63	*[1]*	5.02	*[2]*	[2.0]
VEC(4)	6.41	*[6]*	5.10	*[5]*	5.19	*[5]*	[5.3]
Comb(1-6)	4.36	*[2]*	3.98	*[4]*	4.94	*[1]*	[2.3]
4-quarter							
RW	9.97	*[3]*	7.74	*[2]*	10.69	*[3]*	[2.7]
SP	11.60	*[5]*	8.93	*[6]*	13.03	*[7]*	[6.0]
MS(2)-AR(4)	10.97	*[4]*	8.45	*[4]*	11.93	*[5]*	[4.3]
MS(3)-VEC(4)	17.10	*[6]*	10.90	*[7]*	11.99	*[6]*	[6.3]
ESTAR	9.88	*[2]*	7.89	*[3]*	11.46	*[4]*	[3.0]
VEC(4)	18.10	*[7]*	8.79	*[5]*	10.13	*[2]*	[4.7]
Comb(1-6)	9.14	*[1]*	7.45	*[1]*	9.87	*[1]*	[1.0]
8-quarter							
RW	15.23	*[5]*	11.47	*[6]*	16.53	*[5]*	[5.3]
SP	15.61	*[6]*	11.67	*[7]*	17.72	*[6]*	[6.3]
MS(2)-AR(4)	10.46	*[2]*	8.13	*[2]*	11.51	*[3]*	[2.3]
MS(3)-VEC(4)	14.29	*[4]*	8.57	*[3]*	11.29	*[2]*	[3.0]
ESTAR	11.41	*[3]*	10.89	*[5]*	18.00	*[7]*	[5.0]
VEC(4)	17.47	*[7]*	9.66	*[4]*	16.64	*[4]*	[5.0]
Comb(1-6)	9.80	*[1]*	7.28	*[1]*	10.51	*[1]*	[1.0]

Panel B: 1992:1-1998:4

	Euro	*Rank*	Pound	*Rank*	Yen	*Rank*	*Avg. Rank*
1-quarter							
RW	4.59	*[1]*	4.84	*[2]*	5.01	*[4]*	[2.3]
SP	4.96	*[3]*	4.81	*[1]*	5.31	*[5]*	[3.0]
MS(2)-AR(4)	6.33	*[5]*	6.84	*[6]*	6.20	*[6]*	[5.7]
MS(3)-VEC(4)	8.20	*[7]*	6.97	*[7]*	6.46	*[7]*	[7.0]
ESTAR	4.74	*[2]*	4.91	*[3]*	4.99	*[3]*	[2.7]
VEC(4)	6.88	*[6]*	5.11	*[4]*	4.91	*[2]*	[4.0]
Comb(1-6)	5.08	*[4]*	5.12	*[5]*	4.93	*[1]*	[3.3]
4-quarter							
RW	9.04	*[2]*	8.55	*[2]*	11.13	*[3]*	[2.3]
SP	11.23	*[4]*	9.84	*[5]*	13.82	*[7]*	[5.3]
MS(2)-AR(4)	11.44	*[5]*	10.04	*[6]*	13.34	*[6]*	[5.7]
MS(3)-VEC(4)	20.90	*[6]*	12.71	*[7]*	13.14	*[5]*	[6.0]
ESTAR	9.74	*[3]*	9.00	*[3]*	11.47	*[4]*	[3.3]
VEC(4)	22.17	*[7]*	9.01	*[4]*	10.94	*[2]*	[4.3]
Comb(1-6)	8.95	*[1]*	8.43	*[1]*	10.56	*[1]*	[1.0]
8-quarter							
RW	11.59	*[4]*	20.62	*[6]*	161.55	*[4]*	[4.7]
SP	13.06	*[5]*	21.51	*[7]*	161.71	*[6]*	[6.0]
MS(2)-AR(4)	10.82	*[3]*	19.66	*[4]*	161.02	*[2]*	[3.0]
MS(3)-VEC(4)	16.32	*[7]*	19.65	*[3]*	160.96	*[7]*	[5.7]
ESTAR	9.95	*[2]*	20.45	*[5]*	161.63	*[5]*	[4.0]
VEC(4)	16.06	*[6]*	19.52	*[2]*	161.49	*[3]*	[3.7]
Comb(1-6)	9.42	*[1]*	18.97	*[1]*	160.93	*[1]*	[1.0]

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When considering the full forecasting sample (table 1, panel A) the results indicate that different models are able to beat the random walk at different time horizons.. While at the 1-step-ahead horizon the top-performing model is the ESTAR followed by the Comb(1-6), at 4- and 8-quarter-ahead horizons the MS-AR and MS-VECM models produce more accurate forecasts than the RW model. This evidence also emerges when analysing the first part of the sample (table 1, panel B).

Table 2 provides some insights concerning the difference in the predictive power of linear and non-linear models. The first period, occurring in the early 1990s, embraces the European monetary system crises. During these years, the external value of both the U.K. pound and the euro fell while the Japanese Yen appreciated. Actual exchange rates appear to be better approximated by nonlinear models.

The second period covers the years 1995-1998. These years are characterized by a relatively stable behaviour of the two European currencies. In contrast, the yen has been depreciating against the U.S. dollar over the entire period.

The third period, ranging from the late 1990s to the early 2000s, embraces the launch of the Euro. In these years the RW forecasts appear to be much closer to the actual exchange rate.

Finally, the fourth period goes from the early 2000s to the end of the sample. During these years the three currencies appreciated against the dollar. Contrary to the results of previous time periods, the forecast ability of the non-linear models seems to be higher than the one of the random walk.

The evidence emerging from these figures corroborates the hypothesis of having more than one state operating during the sample periods. In particular, the results suggest that forecasting performance varies significantly across currencies, across forecast horizons and across sub-samples. However, in general, linear models outperform at short forecast horizons especially when deviations from long-term equilibrium are small. In contrast, nonlinear models with more elaborate mean-reverting components dominate at longer horizons especially when deviations from long-term equilibrium are large.

The RMSE provides a quantitative estimate of the forecasting ability of a specific model, allowing different models to be ranked, but does not provide a formal statistical indication of whether one model is significantly better than another. We also explicitly test the null hypothesis of no difference in the accuracy of the two

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competing forecasts by using forecast encompassing tests. In particular, we use a modified version of the Diebold-Mariano (1995) forecast comparison tests.

Table 2: Comparing Forecast Accuracy

Panel A: 1992:1-1995:1

	Euro	*Rank*	Pound	*Rank*	Yen	*Rank*	*Avg. Rank*
1-quarter							
RW	5.70	*[2]*	6.79	*[2]*	3.92	*[4]*	[2.7]
SP	5.77	*[3]*	6.48	*[1]*	3.97	*[5]*	[3.0]
MS(2)-AR(4)	8.27	*[6]*	9.70	*[7]*	5.29	*[7]*	[6.7]
MS(3)-VEC(4)	10.37	*[7]*	9.33	*[6]*	4.25	*[6]*	[6.3]
ESTAR	6.10	*[4]*	6.95	*[4]*	3.69	*[3]*	[3.7]
VEC(4)	7.63	*[5]*	7.03	*[5]*	3.12	*[1]*	[3.7]
Comb(1-6)	5.61	*[1]*	6.91	*[3]*	3.58	*[2]*	[2.0]
4-quarter							
RW	9.18	*[1]*	11.62	*[3]*	9.92	*[5]*	[3.0]
SP	10.80	*[2]*	11.98	*[4]*	12.04	*[7]*	[4.3]
MS(2)-AR(4)	13.45	*[5]*	13.46	*[6]*	9.19	*[4]*	[5.0]
MS(3)-VEC(4)	20.59	*[6]*	16.93	*[7]*	7.72	*[2]*	[5.0]
ESTAR	11.42	*[4]*	12.36	*[5]*	10.75	*[6]*	[5.0]
VEC(4)	29.45	*[7]*	11.30	*[1]*	7.10	*[1]*	[3.0]
Comb(1-6)	11.34	*[3]*	11.39	*[2]*	8.51	*[3]*	[2.7]
8-quarter							
RW	11.32	*[3]*	29.42	*[6]*	236.15	*[5]*	[4.7]
SP	11.92	*[4]*	30.30	*[7]*	236.21	*[6]*	[5.7]
MS(2)-AR(4)	13.16	*[5]*	28.09	*[3]*	235.73	*[3]*	[3.7]
MS(3)-VEC(4)	15.46	*[7]*	28.27	*[4]*	235.70	*[2]*	[4.3]
ESTAR	10.15	*[1]*	28.98	*[5]*	236.29	*[7]*	[4.3]
VEC(4)	14.95	*[6]*	27.41	*[2]*	235.82	*[4]*	[4.0]
Comb(1-6)	10.89	*[2]*	19.38	*[1]*	234.74	*[1]*	[1.3]

Panel B: 1995:1 - 1998:1

	Euro	*Rank*	Pound	*Rank*	Yen	*Rank*	*Avg. Rank*
1-quarter							
RW	3.26	*[1]*	1.79	*[2]*	6.10	*[1]*	[1.3]
SP	4.11	*[5]*	2.01	*[4]*	6.42	*[4]*	[4.3]
MS(2)-AR(4)	4.04	*[4]*	2.03	*[5]*	7.37	*[6]*	[5.0]
MS(3)-VEC(4)	5.71	*[7]*	3.42	*[7]*	8.42	*[7]*	[7.0]
ESTAR	3.07	*[2]*	1.85	*[3]*	6.26	*[3]*	[2.7]
VEC(4)	4.91	*[6]*	2.06	*[6]*	6.46	*[5]*	[5.7]
Comb(1-6)	3.61	*[3]*	1.62	*[1]*	6.25	*[2]*	[2.0]
4-quarter							
RW	9.11	*[4]*	4.35	*[2]*	12.62	*[2]*	[2.7]
SP	12.08	*[5]*	6.42	*[5]*	15.56	*[5]*	[5.0]
MS(2)-AR(4)	8.75	*[3]*	5.40	*[4]*	17.23	*[6]*	[4.3]
MS(3)-VEC(4)	16.87	*[7]*	7.55	*[7]*	17.60	*[7]*	[7.0]
ESTAR	7.25	*[2]*	4.66	*[3]*	12.17	*[1]*	[2.0]
VEC(4)	12.13	*[6]*	6.58	*[6]*	14.38	*[4]*	[5.3]
Comb(1-6)	5.40	*[1]*	4.07	*[1]*	13.00	*[3]*	[1.7]
8-quarter							
RW	12.23	*[4]*	4.29	*[2]*	19.11	*[5]*	[3.7]
SP	14.58	*[5]*	8.17	*[7]*	20.55	*[6]*	[6.0]
MS(2)-AR(4)	8.31	*[1]*	6.14	*[5]*	16.46	*[3]*	[3.0]
MS(3)-VEC(4)	15.79	*[6]*	5.63	*[3]*	15.68	*[2]*	[3.7]
ESTAR	10.42	*[3]*	5.98	*[4]*	17.88	*[4]*	[3.7]
VEC(4)	16.19	*[7]*	7.27	*[6]*	23.17	*[7]*	[6.7]
Comb(1-6)	8.45	*[2]*	3.51	*[1]*	13.21	*[1]*	[1.3]

Panel C: 1998:1 - 2001:1

	Euro	*Rank*	Pound	*Rank*	Yen	*Rank*	*Avg. Rank*
1-quarter							
RW	4.14	*[2]*	2.13	*[1]*	6.10	*[5]*	[2.7]
SP	4.45	*[4]*	2.18	*[2]*	5.74	*[1]*	[2.3]
MS(2)-AR(4)	4.22	*[3]*	2.19	*[3]*	7.10	*[6]*	[4.0]
MS(3)-VEC(4)	4.33	*[4]*	4.77	*[7]*	7.79	*[7]*	[6.0]
ESTAR	4.52	*[5]*	2.28	*[5]*	5.94	*[4]*	[4.7]
VEC(4)	4.84	*[6]*	2.81	*[6]*	5.63	*[2]*	[4.7]
Comb(1-6)	3.85	*[1]*	2.26	*[4]*	5.84	*[3]*	[2.7]
4-quarter							
RW	9.73	*[3]*	5.26	*[4]*	11.54	*[3]*	[2.3]
SP	12.77	*[6]*	4.88	*[1]*	12.55	*[5]*	[5.3]
MS(2)-AR(4)	9.03	*[1]*	5.83	*[5]*	11.69	*[4]*	[3.0]
MS(3)-VEC(4)	10.59	*[4]*	8.40	*[4]*	12.77	*[7]*	[5.7]
ESTAR	11.75	*[5]*	7.28	*[6]*	12.35	*[6]*	[4.7]
VEC(4)	14.08	*[7]*	5.10	*[3]*	11.17	*[2]*	[3.7]
Comb(1-6)	9.22	*[2]*	4.90	*[2]*	10.14	*[1]*	[1.7]
8-quarter							
RW	15.09	*[5]*	7.37	*[5]*	16.65	*[5]*	[5.0]
SP	17.01	*[7]*	7.30	*[4]*	13.97	*[4]*	[5.0]
MS(2)-AR(4)	9.48	*[1]*	5.42	*[2]*	12.28	*[3]*	[2.0]
MS(3)-VEC(4)	12.12	*[3]*	6.32	*[3]*	12.11	*[2]*	[2.7]
ESTAR	13.12	*[4]*	9.08	*[7]*	17.54	*[7]*	[6.0]
VEC(4)	16.81	*[6]*	7.56	*[6]*	17.12	*[6]*	[6.0]
Comb(1-6)	9.98	*[2]*	4.52	*[1]*	9.74	*[1]*	[1.3]

Panel D: 2001:1-2005:2

	Euro	*Rank*	Pound	*Rank*	Yen	*Rank*	*Avg. Rank*
1-quarter							
RW	4.35	*[3]*	2.94	*[2]*	4.11	*[3]*	[2.7]
SP	4.35	*[4]*	2.96	*[3]*	4.19	*[5]*	[4.0]
MS(2)-AR(4)	5.94	*[6]*	3.62	*[5]*	4.13	*[4]*	[5.0]
MS(3)-VEC(4)	5.13	*[5]*	3.97	*[6]*	4.31	*[6]*	[5.7]
ESTAR	4.21	*[2]*	2.54	*[1]*	3.81	*[2]*	[1.7]
VEC(4)	7.79	*[7]*	6.35	*[7]*	4.77	*[7]*	[7.0]
Comb(1-6)	4.42	*[1]*	3.20	*[4]*	3.80	*[1]*	[2.0]
4-quarter							
RW	10.69	*[5]*	7.85	*[4]*	8.20	*[3]*	[4.3]
SP	10.68	*[4]*	8.93	*[5]*	12.31	*[7]*	[4.7]
MS(2)-AR(4)	10.83	*[6]*	7.81	*[3]*	8.38	*[5]*	[6.0]
MS(3)-VEC(4)	11.44	*[7]*	9.78	*[7]*	8.33	*[4]*	[4.0]
ESTAR	8.07	*[1]*	7.24	*[1]*	9.15	*[6]*	[4.3]
VEC(4)	9.78	*[3]*	9.71	*[6]*	7.35	*[1]*	[2.0]
Comb(1-6)	8.57	*[2]*	7.60	*[2]*	7.68	*[2]*	[2.0]
8-quarter							
RW	19.95	*[7]*	13.70	*[7]*	11.94	*[4]*	[6.0]
SP	19.61	*[5]*	13.01	*[6]*	16.10	*[7]*	[6.0]
MS(2)-AR(4)	11.88	*[1]*	8.46	*[1]*	7.92	*[1]*	[1.0]
MS(3)-VEC(4)	12.88	*[3]*	9.36	*[3]*	8.98	*[3]*	[3.0]
ESTAR	13.52	*[4]*	11.96	*[4]*	14.29	*[6]*	[4.7]
VEC(4)	19.77	*[6]*	12.00	*[5]*	13.83	*[5]*	[5.3]
Comb(1-6)	12.01	*[2]*	9.03	*[2]*	8.96	*[2]*	[2.0]

More precisely, the accuracy of the alternative forecasts can be judged according to some loss function, $g(.)$. In analysing formal tests of the null hypothesis of equal forecast accuracy, we follow Diebold and Mariano (1995) and define the loss function as a function of the forecast errors. The loss differential is then denoted as

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$d_t = g(e_{1t}) - g(e_{2t})$ [9], where e_{1t} and e_{2t} are the forecast errors at time t of the model 1 and 2. The null hypothesis of unconditional equal forecast accuracy in this context is that the loss differential has mean 0, i.e. $H_0: E[d_t] = 0$. According to the null hypothesis the errors associated with the two forecasts are equally costly, on average. If the null is rejected, the forecasting method that yields the smallest loss is preferred. Given a series, $\{d_t\}_{t=1}^{T}$, of loss differentials, the test of forecast accuracy is based on:

[14] $$\bar{d} = \frac{1}{T}\sum_{t=1}^{T} d_t$$

The Diebold and Mariano (1995) (*DM*) parametric test is a well-known procedure for testing the null hypothesis of no difference in the accuracy of two competing forecasts. It is given by:

[15] $$DM = \bar{d}\left[2\pi \sum_{\tau=-(T-1)}^{(T-1)} l\left(\tau / s(t)\right) \sum_{t=|\tau|+1}^{T} \left(d_t + \bar{d}\right)\left(d_{t-|\tau|} - \bar{d}\right)\right]^{-\frac{1}{2}}$$

where $l\left(\tau / s(t)\right)$ is the lag window[10], $s(t)$ is the truncation lag and T the number of observations. Harvey, et al. (1997) propose a modified version of the Diebold-Mariano test statistic in order to adjust for the possible wrong size of the original test when the forecasting horizon, k increases. The statistic they proposed is:

[16] $$MDM = T^{-1/2}\left[T + 1 - 2k + T^{-1}k\left(k-1\right)\right]^{1/2} DM$$

We follow the suggestion of Harvey et al. (1997) in comparing the statistics with critical values from the Student's t distribution with (T-1) degrees of freedom, rather than from the standard normal distribution.

Table 3 to 5 report the modified DM and the Granger and Newbold[11] test statistics of equal forecast accuracy (as measured by MSE) and the associated probabilities under the null (of equal accuracy). P-values (in square brackets) no greater the 0.05 suggest that Model *i* produces a lower forecast error (in terms of root

[9] The loss function is defined as $d_t = g(e_{1t})^2 - g(e_{2t})^2$ and $d_t = |g(e_{1t})| - |g(e_{2t})|$ for MSE and MAE, respectively.

[10] This term is computed by using the Newey-West lag window.

[11] See Granger and Newbold (1976) for a detailed description of the test.

mean squared error) relative to the Model *j* at the 5% significance level. In contrast, p-values no smaller then 0.95 mean that Model *i* generates a higher forecast error at the 5% level.

In absolute terms, if we consider the number of times each model significantly beats its competitors according to the two test statistics, we have different results depending on the forecast horizon. More precisely, at 1-quarter-ahead horizon, ESTAR models outperform the others 50% of the times. At 4- and 8- quarter horizon, combined forecasts are found to be the top-performing models. Of a total of 18 cases (six competitors for each of the three currencies), the percentage of times the combined forecast models beat the other models is higher than 60%. This evidence is in line with the results obtained with the RMSE in table 1 and 2.

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Table 3: MDM and GN Tests: Model *i* vs. Model *j* (1-quarter-ahead)

		Diebold-Mariano						Granger-Newbold					
		Euro		Pound		Yen		Euro		Pound		Yen	
Model i	*Model j*	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value
RW	SP	-1.08	*[0.14]*	0.25	*[0.50]*	0.03	*[0.51]*	-0.80	*[0.21]*	0.24	*[0.60]*	-0.22	*[0.41]*
	MS(2)-AR(4)	-2.43	*[0.01]*	-2.11	*[0.02]*	-1.85	*[0.03]*	-2.83	*[0.00]*	-3.25	*[0.00]*	-1.40	*[0.08]*
	VEC(4)	-3.07	*[0.00]*	-2.46	*[0.01]*	-0.23	*[0.41]*	-3.96	*[0.00]*	-2.86	*[0.00]*	-0.28	*[0.39]*
	MS(3)-VEC(4)	-2.77	*[0.00]*	-2.83	*[0.00]*	-2.43	*[0.01]*	-3.52	*[0.00]*	-4.19	*[0.00]*	-1.98	*[0.03]*
	ESTAR	-0.43	*[0.33]*	0.16	*[0.56]*	0.25	*[0.60]*	-0.18	*[0.43]*	0.72	*[0.76]*	0.52	*[0.70]*
	Comb(1-6)	-0.62	*[0.27]*	-1.18	*[0.12]*	0.54	*[0.70]*	-2.00	*[0.02]*	-6.45	*[0.00]*	-49.09	*[0.00]*
SP	RW	1.08	*[0.86]*	-8.50	*[0.50]*	-0.03	*[0.49]*	0.80	*[0.79]*	-0.24	*[0.40]*	0.22	*[0.59]*
	MS(2)-AR(4)	-2.37	*[0.01]*	-2.04	*[0.02]*	-1.96	*[0.02]*	-2.71	*[0.00]*	-3.34	*[0.00]*	-1.39	*[0.09]*
	VEC(4)	-2.91	*[0.00]*	-2.30	*[0.01]*	-0.32	*[0.37]*	-3.82	*[0.00]*	-2.63	*[0.01]*	-0.15	*[0.44]*
	MS(3)-VEC(4)	-2.73	*[0.00]*	-2.69	*[0.00]*	-2.60	*[0.00]*	-3.44	*[0.00]*	-4.38	*[0.00]*	-2.08	*[0.02]*
	ESTAR	0.71	*[0.76]*	0.10	*[0.54]*	0.32	*[0.63]*	0.69	*[0.75]*	0.15	*[0.56]*	0.84	*[0.80]*
	Comb(1-6)	0.17	*[0.57]*	-0.89	*[0.19]*	0.77	*[0.78]*	-1.78	*[0.04]*	-6.66	*[0.00]*	-47.97	*[0.00]*
MS(2)-AR(4)	RW	2.43	*[0.99]*	2.11	*[0.98]*	1.85	*[0.97]*	2.83	*[1.00]*	3.25	*[1.00]*	1.40	*[0.92]*
	SP	2.37	*[0.99]*	2.04	*[0.98]*	1.96	*[0.98]*	2.71	*[1.00]*	3.34	*[1.00]*	1.39	*[0.91]*
	VEC(4)	-0.76	*[0.22]*	0.22	*[0.59]*	1.60	*[0.95]*	-1.43	*[0.08]*	0.60	*[0.73]*	1.14	*[0.87]*
	MS(3)-VEC(4)	-1.85	*[0.03]*	-1.54	*[0.06]*	-1.34	*[0.09]*	-1.82	*[0.04]*	-1.74	*[0.04]*	-1.40	*[0.08]*
	ESTAR	2.50	*[0.99]*	2.37	*[0.99]*	2.14	*[0.98]*	2.93	*[1.00]*	3.82	*[1.00]*	1.75	*[0.96]*
	Comb(1-6)	2.88	*[1.00]*	2.21	*[0.99]*	2.93	*[1.00]*	1.10	*[0.86]*	-3.60	*[0.00]*	-42.55	*[0.00]*
VEC(4)	RW	3.07	*[1.00]*	2.46	*[0.99]*	0.23	*[0.59]*	3.96	*[1.00]*	2.86	*[1.00]*	0.28	*[0.61]*
	SP	2.91	*[1.00]*	2.30	*[0.99]*	0.32	*[0.63]*	3.82	*[1.00]*	2.63	*[0.99]*	0.15	*[0.56]*
	MS(2)-AR(4)	0.76	*[0.78]*	-0.22	*[0.41]*	-1.60	*[0.05]*	1.43	*[0.92]*	-0.60	*[0.27]*	-1.14	*[0.13]*
	MS(3)-VEC(4)	-0.13	*[0.45]*	-0.87	*[0.19]*	-2.38	*[0.01]*	0.31	*[0.62]*	-1.60	*[0.06]*	-1.79	*[0.04]*
	ESTAR	2.96	*[1.00]*	2.43	*[0.99]*	0.55	*[0.71]*	4.09	*[1.00]*	3.28	*[1.00]*	0.72	*[0.76]*
	Comb(1-6)	2.89	*[1.00]*	1.92	*[0.97]*	0.87	*[0.81]*	2.52	*[0.99]*	-3.81	*[0.00]*	-47.79	*[0.00]*
MS(3)-VEC(4)	RW	2.77	*[1.00]*	2.83	*[1.00]*	2.43	*[0.99]*	3.52	*[1.00]*	4.19	*[1.00]*	1.98	*[0.97]*
	SP	2.73	*[1.00]*	2.69	*[1.00]*	2.60	*[1.00]*	3.44	*[1.00]*	4.38	*[1.00]*	2.08	*[0.98]*
	MS(2)-AR(4)	1.85	*[0.97]*	1.54	*[0.94]*	1.34	*[0.91]*	1.82	*[0.96]*	1.74	*[0.96]*	1.40	*[0.92]*
	VEC(4)	0.13	*[0.55]*	0.87	*[0.81]*	2.38	*[0.99]*	-0.31	*[0.38]*	1.60	*[0.94]*	1.79	*[0.96]*
	ESTAR	2.89	*[1.00]*	3.20	*[1.00]*	2.95	*[1.00]*	3.72	*[1.00]*	4.67	*[1.00]*	2.43	*[0.99]*
	Comb(1-6)	3.24	*[1.00]*	3.21	*[1.00]*	3.69	*[1.00]*	2.41	*[0.99]*	-2.80	*[0.00]*	-40.23	*[0.00]*
ESTAR	RW	0.43	*[0.67]*	-0.16	*[0.44]*	-0.25	*[0.40]*	0.18	*[0.57]*	-0.72	*[0.24]*	-0.52	*[0.30]*
	SP	-0.71	*[0.24]*	-0.10	*[0.46]*	-0.32	*[0.37]*	-0.69	*[0.25]*	-0.15	*[0.44]*	-0.84	*[0.20]*
	MS(2)-AR(4)	-2.50	*[0.01]*	-2.37	*[0.01]*	-2.14	*[0.02]*	-2.93	*[0.00]*	-3.82	*[0.00]*	-1.75	*[0.04]*
	VEC(4)	-2.96	*[0.00]*	-2.43	*[0.01]*	-0.55	*[0.29]*	-4.09	*[0.00]*	-3.28	*[0.00]*	-0.72	*[0.24]*
	MS(3)-VEC(4)	-2.89	*[0.00]*	-3.20	*[0.00]*	-2.95	*[0.00]*	-3.72	*[0.00]*	-4.67	*[0.00]*	-2.43	*[0.01]*
	Comb(1-6)	-0.38	*[0.35]*	-2.24	*[0.01]*	0.38	*[0.65]*	-2.00	*[0.03]*	-6.78	*[0.00]*	-51.72	*[0.00]*
Comb(1-6)	RW	0.62	*[0.73]*	1.18	*[0.88]*	-0.54	*[0.30]*	2.00	*[0.98]*	6.45	*[1.00]*	49.09	*[1.00]*
	SP	-0.17	*[0.43]*	0.89	*[0.81]*	-0.77	*[0.22]*	1.78	*[0.96]*	6.66	*[1.00]*	47.97	*[1.00]*
	MS(2)-AR(4)	-2.88	*[0.00]*	-2.21	*[0.01]*	-2.93	*[0.00]*	-1.10	*[0.14]*	3.60	*[1.00]*	42.55	*[1.00]*
	VEC(4)	-2.89	*[0.00]*	-1.92	*[0.03]*	-0.87	*[0.19]*	-2.52	*[0.01]*	3.81	*[1.00]*	47.79	*[1.00]*
	MS(3)-VEC(4)	-3.24	*[0.00]*	-3.21	*[0.00]*	-3.69	*[0.00]*	-2.41	*[0.01]*	2.80	*[1.00]*	40.23	*[1.00]*
	ESTAR	0.38	*[0.65]*	2.24	*[0.99]*	-0.38	*[0.35]*	2.00	*[0.97]*	6.78	*[1.00]*	51.72	*[1.00]*

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Table 4: MDM and GN Tests: Model *i* vs. Model *j* (4-quarter-ahead)

		Diebold-Mariano						Granger-Newbold					
		Euro		Pound		Yen		Euro		Pound		Yen	
Model i	*Model j*	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value
RW	SP	-2.30	*[0.01]*	-1.99	*[0.02]*	-2.44	*[0.01]*	-2.50	*[0.01]*	-0.57	*[0.28]*	-0.08	*[0.47]*
	MS(2)-AR(4)	-1.31	*[0.10]*	-1.76	*[0.04]*	-1.40	*[0.08]*	-1.39	*[0.08]*	-0.77	*[0.22]*	1.18	*[0.88]*
	VEC(4)	-1.87	*[0.03]*	-1.30	*[0.10]*	0.86	*[0.81]*	-5.08	*[0.00]*	1.19	*[0.88]*	1.76	*[0.96]*
	MS(3)-VEC(4)	-2.87	*[0.00]*	-3.52	*[0.00]*	-1.41	*[0.08]*	-4.04	*[0.00]*	-3.76	*[0.00]*	1.53	*[0.93]*
	ESTAR	0.12	*[0.55]*	-0.43	*[0.33]*	-1.21	*[0.11]*	0.00	*[0.50]*	-1.63	*[0.05]*	-1.14	*[0.13]*
	Comb(1-6)	1.37	*[0.91]*	1.61	*[0.95]*	2.49	*[0.99]*	1.23	*[0.89]*	-2.19	*[0.02]*	1.41	*[0.92]*
SP	RW	2.30	*[0.99]*	1.99	*[0.98]*	2.44	*[0.99]*	2.50	*[0.99]*	0.57	*[0.72]*	0.08	*[0.53]*
	MS(2)-AR(4)	0.55	*[0.71]*	0.63	*[0.74]*	0.80	*[0.79]*	0.66	*[0.74]*	0.06	*[0.53]*	0.69	*[0.75]*
	VEC(4)	-1.58	*[0.06]*	0.15	*[0.56]*	2.22	*[0.99]*	-3.25	*[0.00]*	1.10	*[0.86]*	0.90	*[0.82]*
	MS(3)-VEC(4)	-2.24	*[0.01]*	-1.82	*[0.03]*	0.75	*[0.77]*	-2.47	*[0.01]*	-1.92	*[0.03]*	0.82	*[0.79]*
	ESTAR	1.78	*[0.96]*	1.38	*[0.92]*	1.17	*[0.88]*	1.67	*[0.95]*	-0.17	*[0.43]*	-0.50	*[0.31]*
	Comb(1-6)	3.18	*[1.00]*	2.36	*[0.99]*	3.08	*[1.00]*	2.57	*[0.99]*	-1.70	*[0.05]*	0.55	*[0.71]*
MS(2)-AR(4)	RW	1.31	*[0.90]*	1.76	*[0.96]*	1.40	*[0.92]*	1.39	*[0.92]*	0.77	*[0.78]*	-1.18	*[0.12]*
	SP	-0.55	*[0.29]*	-0.63	*[0.26]*	-0.80	*[0.21]*	-0.66	*[0.26]*	-0.06	*[0.47]*	-0.69	*[0.25]*
	VEC(4)	-1.79	*[0.04]*	-0.55	*[0.29]*	2.63	*[1.00]*	-4.40	*[0.00]*	1.81	*[0.96]*	0.34	*[0.63]*
	MS(3)-VEC(4)	-2.93	*[0.00]*	-2.76	*[0.00]*	-0.18	*[0.43]*	-4.04	*[0.00]*	-3.34	*[0.00]*	0.26	*[0.60]*
	ESTAR	1.19	*[0.88]*	1.13	*[0.87]*	0.43	*[0.67]*	1.20	*[0.88]*	-0.48	*[0.32]*	-1.91	*[0.03]*
	Comb(1-6)	2.38	*[0.99]*	2.86	*[1.00]*	2.63	*[1.00]*	2.57	*[0.99]*	-1.73	*[0.04]*	-0.55	*[0.29]*
VEC(4)	RW	1.87	*[0.97]*	1.30	*[0.90]*	-0.86	*[0.19]*	5.08	*[1.00]*	-1.19	*[0.12]*	-1.76	*[0.04]*
	SP	1.58	*[0.94]*	-0.15	*[0.44]*	-2.22	*[0.01]*	3.25	*[1.00]*	-1.10	*[0.14]*	-0.90	*[0.18]*
	MS(2)-AR(4)	1.79	*[0.96]*	0.55	*[0.71]*	-2.63	*[0.00]*	4.40	*[1.00]*	-1.81	*[0.04]*	-0.34	*[0.37]*
	MS(3)-VEC(4)	0.33	*[0.63]*	-1.71	*[0.04]*	-2.85	*[0.00]*	0.49	*[0.69]*	-3.74	*[0.00]*	-0.25	*[0.40]*
	ESTAR	2.01	*[0.98]*	1.05	*[0.85]*	-1.49	*[0.07]*	6.24	*[1.00]*	-2.86	*[0.00]*	-2.86	*[0.00]*
	Comb(1-6)	2.09	*[0.98]*	1.77	*[0.96]*	0.49	*[0.69]*	6.69	*[1.00]*	-2.68	*[0.00]*	-1.25	*[0.11]*
MS(3)-VEC(4)	RW	2.87	*[1.00]*	3.52	*[1.00]*	1.41	*[0.92]*	4.04	*[1.00]*	3.76	*[1.00]*	-1.53	*[0.07]*
	SP	2.24	*[0.99]*	1.82	*[0.97]*	-0.75	*[0.23]*	2.47	*[0.99]*	1.92	*[0.97]*	-0.82	*[0.21]*
	MS(2)-AR(4)	2.93	*[1.00]*	2.76	*[1.00]*	0.18	*[0.57]*	4.04	*[1.00]*	3.34	*[1.00]*	-0.26	*[0.40]*
	VEC(4)	-0.33	*[0.37]*	1.71	*[0.96]*	2.85	*[1.00]*	-0.49	*[0.31]*	3.74	*[1.00]*	0.25	*[0.60]*
	ESTAR	3.03	*[1.00]*	3.37	*[1.00]*	0.46	*[0.68]*	4.15	*[1.00]*	2.51	*[0.99]*	-2.20	*[0.02]*
	Comb(1-6)	3.27	*[1.00]*	3.82	*[1.00]*	2.62	*[1.00]*	5.80	*[1.00]*	0.32	*[0.63]*	-0.88	*[0.19]*
ESTAR	RW	-0.12	*[0.45]*	0.43	*[0.67]*	1.21	*[0.89]*	0.00	*[0.50]*	1.63	*[0.95]*	1.14	*[0.87]*
	SP	-1.78	*[0.04]*	-1.38	*[0.08]*	-1.17	*[0.12]*	-1.67	*[0.05]*	0.17	*[0.57]*	0.50	*[0.69]*
	MS(2)-AR(4)	-1.19	*[0.12]*	-1.13	*[0.13]*	-0.43	*[0.33]*	-1.20	*[0.12]*	0.48	*[0.68]*	1.91	*[0.97]*
	VEC(4)	-2.01	*[0.02]*	-1.05	*[0.15]*	1.49	*[0.93]*	-6.24	*[0.00]*	2.86	*[1.00]*	2.86	*[1.00]*
	MS(3)-VEC(4)	-3.03	*[0.00]*	-3.37	*[0.00]*	-0.46	*[0.32]*	-4.15	*[0.00]*	-2.51	*[0.01]*	2.20	*[0.98]*
	Comb(1-6)	0.91	*[0.82]*	1.30	*[0.90]*	2.08	*[0.98]*	1.16	*[0.87]*	-1.56	*[0.06]*	2.39	*[0.99]*
Comb(1-6)	RW	-1.37	*[0.09]*	-1.61	*[0.05]*	-2.49	*[0.01]*	-1.23	*[0.11]*	2.19	*[0.98]*	-1.41	*[0.08]*
	SP	-3.18	*[0.00]*	-2.36	*[0.01]*	-3.08	*[0.00]*	-2.57	*[0.01]*	1.70	*[0.95]*	-0.55	*[0.29]*
	MS(2)-AR(4)	-2.38	*[0.01]*	-2.86	*[0.00]*	-2.63	*[0.00]*	-2.57	*[0.01]*	1.73	*[0.96]*	0.55	*[0.71]*
	VEC(4)	-2.09	*[0.02]*	-1.77	*[0.04]*	-0.49	*[0.31]*	-6.69	*[0.00]*	2.68	*[1.00]*	1.25	*[0.89]*
	MS(3)-VEC(4)	-3.27	*[0.00]*	-3.82	*[0.00]*	-2.62	*[0.00]*	-5.80	*[0.00]*	-0.32	*[0.37]*	0.88	*[0.81]*
	ESTAR	-0.91	*[0.18]*	-1.30	*[0.10]*	-2.08	*[0.02]*	-1.16	*[0.13]*	1.56	*[0.94]*	-2.39	*[0.01]*

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Table 5: MDM and GN Tests: Model *i* vs. Model *j* (8-quarter-ahead)

		Diebold-Mariano						Granger-Newbold					
		Euro		Pound		Yen		Euro		Pound		Yen	
Model i	*Model j*	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value
RW	SP	-0.51	*[0.31]*	-0.31	*[0.38]*	-1.06	*[0.14]*	-0.69	*[0.25]*	1.29	*[0.90]*	0.41	*[0.66]*
	MS(2)-AR(4)	3.83	*[1.00]*	3.01	*[1.00]*	3.57	*[1.00]*	3.92	*[1.00]*	2.09	*[0.98]*	1.46	*[0.92]*
	VEC(4)	-1.61	*[0.05]*	2.11	*[0.98]*	-0.09	*[0.46]*	-1.42	*[0.08]*	5.67	*[1.00]*	4.32	*[1.00]*
	MS(3)-VEC(4)	0.65	*[0.74]*	2.69	*[1.00]*	3.66	*[1.00]*	0.54	*[0.70]*	1.59	*[0.94]*	1.80	*[0.96]*
	ESTAR	3.79	*[1.00]*	0.92	*[0.82]*	-1.54	*[0.06]*	3.79	*[1.00]*	-1.46	*[0.07]*	-2.91	*[0.00]*
	Comb(1-6)	5.50	*[1.00]*	5.42	*[1.00]*	6.89	*[1.00]*	6.00	*[1.00]*	3.12	*[1.00]*	1.55	*[0.94]*
SP	RW	0.51	*[0.69]*	0.31	*[0.62]*	1.06	*[0.86]*	0.69	*[0.75]*	-1.29	*[0.10]*	-0.41	*[0.34]*
	MS(2)-AR(4)	4.02	*[1.00]*	3.93	*[1.00]*	3.90	*[1.00]*	3.81	*[1.00]*	1.20	*[0.88]*	0.87	*[0.81]*
	VEC(4)	-1.39	*[0.08]*	2.51	*[0.99]*	0.64	*[0.74]*	-1.10	*[0.14]*	2.99	*[1.00]*	1.87	*[0.97]*
	MS(3)-VEC(4)	0.86	*[0.80]*	3.42	*[1.00]*	4.02	*[1.00]*	0.77	*[0.78]*	0.71	*[0.76]*	1.16	*[0.88]*
	ESTAR	4.44	*[1.00]*	0.86	*[0.80]*	-0.18	*[0.43]*	3.99	*[1.00]*	-1.86	*[0.03]*	-1.98	*[0.03]*
	Comb(1-6)	5.21	*[1.00]*	5.84	*[1.00]*	5.58	*[1.00]*	5.40	*[1.00]*	1.43	*[0.92]*	0.73	*[0.77]*
MS(2)-AR(4)	RW	-3.83	*[0.00]*	-3.01	*[0.00]*	-3.57	*[0.00]*	-3.92	*[0.00]*	-2.09	*[0.02]*	-1.46	*[0.08]*
	SP	-4.02	*[0.00]*	-3.93	*[0.00]*	-3.90	*[0.00]*	-3.81	*[0.00]*	-1.20	*[0.12]*	-0.87	*[0.19]*
	VEC(4)	-4.58	*[0.00]*	-1.51	*[0.07]*	-2.98	*[0.00]*	-3.93	*[0.00]*	1.09	*[0.86]*	0.72	*[0.76]*
	MS(3)-VEC(4)	-3.88	*[0.00]*	-1.70	*[0.04]*	0.48	*[0.68]*	-3.17	*[0.00]*	-1.73	*[0.04]*	1.16	*[0.88]*
	ESTAR	-0.76	*[0.22]*	-2.57	*[0.01]*	-3.65	*[0.00]*	-0.84	*[0.20]*	-3.13	*[0.00]*	-3.59	*[0.00]*
	Comb(1-6)	0.95	*[0.83]*	1.06	*[0.86]*	1.02	*[0.85]*	0.76	*[0.77]*	-0.11	*[0.46]*	-0.70	*[0.24]*
VEC(4)	RW	1.61	*[0.95]*	-2.11	*[0.02]*	0.09	*[0.54]*	1.42	*[0.92]*	-5.67	*[0.00]*	-4.32	*[0.00]*
	SP	1.39	*[0.92]*	-2.51	*[0.01]*	-0.64	*[0.26]*	1.10	*[0.86]*	-2.99	*[0.00]*	-1.87	*[0.03]*
	MS(2)-AR(4)	4.58	*[1.00]*	1.51	*[0.93]*	2.98	*[1.00]*	3.93	*[1.00]*	-1.09	*[0.14]*	-0.72	*[0.24]*
	MS(3)-VEC(4)	2.19	*[0.99]*	1.01	*[0.84]*	3.17	*[1.00]*	1.49	*[0.93]*	-1.58	*[0.06]*	-0.41	*[0.34]*
	ESTAR	5.98	*[1.00]*	-1.14	*[0.13]*	-0.73	*[0.23]*	5.53	*[1.00]*	-10.34	*[0.00]*	-5.78	*[0.00]*
	Comb(1-6)	5.73	*[1.00]*	3.04	*[1.00]*	4.18	*[1.00]*	5.43	*[1.00]*	-1.85	*[0.03]*	-1.62	*[0.06]*
MS(3)-VEC(4)	RW	-0.65	*[0.26]*	-2.69	*[0.00]*	-3.66	*[0.00]*	-0.54	*[0.30]*	-1.59	*[0.06]*	-1.80	*[0.04]*
	SP	-0.86	*[0.20]*	-3.42	*[0.00]*	-4.02	*[0.00]*	-0.77	*[0.22]*	-0.71	*[0.24]*	-1.16	*[0.12]*
	MS(2)-AR(4)	3.88	*[1.00]*	1.70	*[0.96]*	-0.48	*[0.32]*	3.17	*[1.00]*	1.73	*[0.96]*	-1.16	*[0.12]*
	VEC(4)	-2.19	*[0.01]*	-1.01	*[0.16]*	-3.17	*[0.00]*	-1.49	*[0.07]*	1.58	*[0.94]*	0.41	*[0.66]*
	ESTAR	1.92	*[0.97]*	-2.21	*[0.01]*	-3.53	*[0.00]*	1.44	*[0.92]*	-2.47	*[0.01]*	-3.90	*[0.00]*
	Comb(1-6)	3.90	*[1.00]*	1.61	*[0.95]*	0.75	*[0.77]*	3.26	*[1.00]*	0.85	*[0.80]*	-1.36	*[0.09]*
ESTAR	RW	-3.79	*[0.00]*	-0.92	*[0.18]*	1.54	*[0.94]*	-3.79	*[0.00]*	1.46	*[0.93]*	2.91	*[1.00]*
	SP	-4.44	*[0.00]*	-0.86	*[0.20]*	0.18	*[0.57]*	-3.99	*[0.00]*	1.86	*[0.97]*	1.98	*[0.97]*
	MS(2)-AR(4)	0.76	*[0.78]*	2.57	*[0.99]*	3.65	*[1.00]*	0.84	*[0.80]*	3.13	*[1.00]*	3.59	*[1.00]*
	VEC(4)	-5.98	*[0.00]*	1.14	*[0.87]*	0.73	*[0.77]*	-5.53	*[0.00]*	10.34	*[1.00]*	5.78	*[1.00]*
	MS(3)-VEC(4)	-1.92	*[0.03]*	2.21	*[0.99]*	3.53	*[1.00]*	-1.44	*[0.08]*	2.47	*[0.99]*	3.90	*[1.00]*
	Comb(1-6)	1.81	*[0.96]*	4.54	*[1.00]*	5.33	*[1.00]*	1.86	*[0.97]*	5.19	*[1.00]*	5.36	*[1.00]*
Comb(1-6)	RW	-5.50	*[0.00]*	-5.42	*[0.00]*	-6.89	*[0.00]*	-6.00	*[0.00]*	-3.12	*[0.00]*	-1.55	*[0.06]*
	SP	-5.21	*[0.00]*	-5.84	*[0.00]*	-5.58	*[0.00]*	-5.40	*[0.00]*	-1.43	*[0.08]*	-0.73	*[0.23]*
	MS(2)-AR(4)	-0.95	*[0.17]*	-1.06	*[0.14]*	-1.02	*[0.15]*	-0.76	*[0.23]*	0.11	*[0.54]*	0.70	*[0.76]*
	VEC(4)	-5.73	*[0.00]*	-3.04	*[0.00]*	-4.18	*[0.00]*	-5.43	*[0.00]*	1.85	*[0.97]*	1.62	*[0.94]*
	MS(3)-VEC(4)	-3.90	*[0.00]*	-1.61	*[0.05]*	-0.75	*[0.23]*	-3.26	*[0.00]*	-0.85	*[0.20]*	1.36	*[0.91]*
	ESTAR	-1.81	*[0.04]*	-4.54	*[0.00]*	-5.33	*[0.00]*	-1.86	*[0.03]*	-5.19	*[0.00]*	-5.36	*[0.00]*

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4.2 Forecasts Encompassing

Forecast encompassing assesses whether any extra important information is contained in forecasts from rival models. A simple methodology to compare the forecast accuracy has been developed by Fair-Shiller (1990). The testing procedure in the Fair-Shiller approach is based on the following equation:

$$[17] \qquad e_t - e_{t-j} = \alpha + \alpha_{m1}\left(\hat{e}_{m1,t} - e_{t-j}\right) + \alpha_{m2}\left(\hat{e}_{m2,t} - e_{t-j}\right) + \varepsilon_t \qquad j=1,4,8$$

where $\hat{e}_{m1,t}$, and $\hat{e}_{m2,t}$, are the forecasts obtained using model 1 (m1) and 2 (m2), respectively. The intuition behind this testing procedure is straightforward. If both forecasts contain useful and independent information concerning e_t, then the estimates of the slope coefficients α_{m1} and α_{m2} should be significant. In contrast, if the information in one forecast is completely contained in the other, then the coefficient of the second forecast should be nonzero while that of the first one should be zero.

The Fair-Shiller tests results are presented in tables 6, 7 and 8 for the dollar-euro, dollar-pound and dollar-yen exchange rates, respectively. These tables report, for each currency, regression coefficients from equation [17] and the associated t-values at different horizons (1, 4 and 8 quarters ahead).

On the basis of the Fair-Shiller tests and with the notable exception of the Japanese currency none of the selected models outperform their competitors at 1-quarter-ahead horizon. It is interesting to note that when increasing the forecast horizon, combined models dominate the others. In general, the longer the forecast horizon, the worse the RW exchange rate forecasts become.

At 4-quarter-ahead horizon, combined forecasts still produce superior out-of-sample forecasting performance compared to other models. However, in these cases, other models also generate better forecasts if compared to the random walk. In fact, the t-values of the ESTAR and VEC models are above the 95% confidence threshold when compared with the RW, SP and MSAR models. From these tables, we can also conclude that, in most cases, at the 8-querter horizon, the forecast accuracy of non-linear models significantly outperforms that of the competing models.

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Table 6: Dollar/Euro – Fair and Shiller encompassing test

1-quarter-ahead

m1 / m2		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			-0.03	-0.05	-0.07	-0.12	-0.02	-0.04	0.03	0.05	0.04	0.07	0.04	0.08
	α_1			0.24	0.71	0.09	0.63	0.15	1.54	0.44	1.54	0.11	1.05	0.42	1.63
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	-0.03	-0.05			-0.05	-0.08	-0.02	-0.04	0.04	0.07	0.04	0.06	0.06	0.10
	α_1	0.00	0.00			0.05	0.32	0.15	1.35	0.59	1.44	0.09	0.83	0.58	1.58
	α_2	0.24	0.71			0.18	0.47	0.01	0.04	-0.24	-0.51	0.13	0.35	-0.30	-0.62
MSAR	c	-0.07	-0.12	-0.05	-0.08			0.04	0.07	0.03	0.05	0.02	0.03	0.11	0.19
	α_1	0.00	0.00	0.18	0.47			0.26	1.65	0.44	1.39	0.10	1.00	0.59	1.65
	α_2	0.09	0.63	0.05	0.32			-0.20	-0.87	0.00	0.02	0.08	0.56	-0.14	-0.69
MSVEC	c	-0.02	-0.04	-0.02	-0.04	0.04	0.07			0.02	0.04	0.04	0.06	0.03	0.04
	α_1	0.00	0.00	0.01	0.04	-0.20	-0.87			0.31	0.96	0.07	0.71	0.29	0.63
	α_2	0.15	1.54	0.15	1.35	0.26	1.65			0.11	0.96	0.14	1.32	0.06	0.36
ESTAR	c	0.03	0.05	0.04	0.07	0.03	0.05	0.02	0.04			0.07	0.12	0.05	0.09
	α_1	0.00	0.00	-0.24	-0.51	0.00	0.02	0.11	0.96			0.06	0.55	0.28	0.77
	α_2	0.44	1.54	0.59	1.44	0.44	1.39	0.31	0.96			0.38	1.24	0.23	0.56
VEC	c	0.04	0.07	0.04	0.06	0.02	0.03	0.04	0.06	0.07	0.12			0.05	0.09
	α_1	0.00	0.00	0.13	0.35	0.08	0.56	0.14	1.32	0.38	1.24			0.39	1.24
	α_2	0.11	1.05	0.09	0.83	0.10	1.00	0.07	0.71	0.06	0.55			0.02	0.14
COMB	c	0.04	0.08	0.06	0.10	0.11	0.19	0.03	0.04	0.05	0.09	0.05	0.09		
	α_1	0.00	0.00	-0.30	-0.62	-0.14	-0.69	0.06	0.36	0.23	0.56	0.02	0.14		
	α_2	0.42	1.63	0.58	1.58	0.59	1.65	0.29	0.63	0.28	0.77	0.39	1.24		

4-quarter-ahead

m1 / m2		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			0.13	0.10	0.19	0.14	0.06	0.05	0.15	0.12	0.25	0.18	0.09	0.07
	α_1			-0.11	-0.43	0.06	0.24	0.08	0.95	0.48	1.89	-0.05	-0.53	0.81	3.40
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	0.13	0.10			0.14	0.10	0.05	0.04	0.14	0.11	0.20	0.15	0.09	0.07
	α_1	0.00	0.00			0.01	0.02	0.08	0.85	0.47	1.83	-0.06	-0.59	0.81	3.34
	α_2	-0.11	-0.43			-0.10	-0.35	-0.03	-0.11	-0.03	-0.10	-0.13	-0.51	0.00	0.02
MSAR	c	0.19	0.14	0.14	0.10			-0.02	-0.01	0.14	0.11	0.28	0.21	0.03	0.02
	α_1	0.00	0.00	-0.10	-0.35			0.13	1.05	0.50	1.89	-0.06	-0.62	0.94	3.64
	α_2	0.06	0.24	0.01	0.02			-0.18	-0.52	-0.09	-0.32	0.11	0.41	-0.33	-1.27
MSVEC	c	0.06	0.05	0.05	0.04	-0.02	-0.01			0.09	0.07	0.14	0.10	0.27	0.22
	α_1	0.00	0.00	-0.03	-0.11	-0.18	-0.52			0.44	1.69	-0.09	-0.90	1.08	3.57
	α_2	0.08	0.95	0.08	0.85	0.13	1.05			0.05	0.51	0.11	1.19	-0.15	-1.42
ESTAR	c	0.15	0.12	0.14	0.11	0.14	0.11	0.09	0.07			0.42	0.33	0.09	0.07
	α_1	0.00	0.00	-0.03	-0.10	-0.09	-0.32	0.05	0.51			-0.23	-2.06	0.74	2.80
	α_2	0.48	1.89	0.47	1.83	0.50	1.89	0.44	1.69			0.84	2.78	0.17	0.64
VEC	c	0.25	0.18	0.20	0.15	0.28	0.21	0.14	0.10	0.42	0.33			0.33	0.28
	α_1	0.00	0.00	-0.13	-0.51	0.11	0.41	0.11	1.19	0.84	2.78			1.05	4.18
	α_2	-0.05	-0.53	-0.06	-0.59	-0.06	-0.62	-0.09	-0.90	-0.23	-2.06			-0.21	-2.31
COMB	c	0.09	0.07	0.09	0.07	0.03	0.02	0.27	0.22	0.09	0.07	0.33	0.28		
	α_1	0.00	0.00	0.00	0.02	-0.33	-1.27	-0.15	-1.42	0.17	0.64	-0.21	-2.31		
	α_2	0.81	3.40	0.81	3.34	0.94	3.64	1.08	3.57	0.74	2.80	1.05	4.18		

8-quarter-ahead

m1 / m2		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			0.56	0.26	-0.81	-0.55	-0.69	-0.38	0.29	0.18	1.04	0.49	-1.17	-0.98
	α_1			0.31	0.78	1.17	7.76	0.57	4.66	1.38	6.80	0.30	1.93	1.66	10.83
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	0.56	0.26			-0.65	-0.44	-0.48	-0.26	0.21	0.13	1.12	0.53	-1.13	-0.93
	α_1	0.00	0.00			1.17	7.72	0.57	4.70	1.40	6.67	0.29	1.80	1.66	10.64
	α_2	0.31	0.78			0.26	0.95	0.36	1.08	-0.13	-0.43	0.18	0.46	0.06	0.25
MSAR	c	-0.81	-0.55	-0.65	-0.44			-0.70	-0.48	-0.53	-0.43	-0.29	-0.20	-1.18	-0.98
	α_1	0.00	0.00	0.26	0.95			-0.18	-1.04	0.87	4.81	0.23	2.11	1.47	5.16
	α_2	1.17	7.76	1.17	7.72			1.40	5.30	0.84	5.80	1.14	7.79	0.18	0.78
MSVEC	c	-0.69	-0.38	-0.48	-0.26	-0.70	-0.48			-0.40	-0.28	-0.02	-0.01	-1.05	-0.91
	α_1	0.00	0.00	0.36	1.08	1.40	5.30			1.15	5.98	0.30	2.32	2.01	8.63
	α_2	0.57	4.66	0.57	4.70	-0.18	-1.04			0.37	3.76	0.57	4.86	-0.24	-1.95
ESTAR	c	0.29	0.18	0.21	0.13	-0.53	-0.43	-0.40	-0.28			-0.79	-0.54	-0.92	-0.79
	α_1	0.00	0.00	-0.13	-0.43	0.84	5.80	0.37	3.76			-0.48	-3.17	1.36	6.68
	α_2	1.38	6.80	1.40	6.67	0.87	4.81	1.15	5.98			1.95	7.53	0.44	2.16
VEC	c	1.04	0.49	1.12	0.53	-0.29	-0.20	-0.02	-0.01	-0.79	-0.54			-1.39	-1.13
	α_1	0.00	0.00	0.18	0.46	1.14	7.79	0.57	4.86	1.95	7.53			1.71	10.28
	α_2	0.30	1.93	0.29	1.80	0.23	2.11	0.30	2.32	-0.48	-3.17			-0.08	-0.81
COMB	c	-1.17	-0.98	-1.13	-0.93	-1.18	-0.98	-1.05	-0.91	-0.92	-0.79	-1.39	-1.13		
	α_1	0.00	0.00	0.06	0.25	0.18	0.78	-0.24	-1.95	0.44	2.16	-0.08	-0.81		
	α_2	1.66	10.83	1.66	10.64	1.47	5.16	2.01	8.63	1.36	6.68	1.71	10.28		

For Peer Review

Table 7: Dollar/Pound – Fair and Shiller encompassing test

1-quarter-ahead

m2 \ m1		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			-0.26	-0.50	-0.18	-0.33	-0.17	-0.32	0.42	0.65	-0.18	-0.30	-0.17	-0.32
	α_1			0.59	1.89	0.04	0.29	-0.01	-0.06	0.94	1.56	0.01	0.04	0.07	0.19
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	-0.26	-0.50			-0.26	-0.49	-0.29	-0.55	0.11	0.16	-0.28	-0.48	-0.27	-0.51
	α_1	0.00	0.00			-0.01	-0.04	-0.06	-0.44	0.56	0.85	0.01	0.09	-0.20	-0.51
	α_2	0.59	1.89			0.59	1.85	0.61	1.93	0.46	1.35	0.59	1.87	0.65	1.93
MSAR	c	-0.18	-0.33	-0.26	-0.49			-0.25	-0.45	0.53	0.76	-0.18	-0.30	-0.19	-0.34
	α_1	0.00	0.00	0.59	1.85			-0.10	-0.48	1.09	1.59	0.00	0.01	-0.10	-0.12
	α_2	0.04	0.29	-0.01	-0.04			0.14	0.55	-0.08	-0.47	0.04	0.28	0.07	0.24
MSVEC	c	-0.17	-0.32	-0.29	-0.55	-0.25	-0.45			0.46	0.70	-0.19	-0.31	-0.25	-0.45
	α_1	0.00	0.00	0.61	1.93	0.14	0.55			1.07	1.67	0.01	0.05	0.49	0.56
	α_2	-0.01	-0.06	-0.06	-0.44	-0.10	-0.48			-0.08	-0.62	-0.01	-0.07	-0.16	-0.53
ESTAR	c	0.42	0.65	0.11	0.16	0.53	0.76	0.46	0.70			0.60	0.79	0.66	0.94
	α_1	0.00	0.00	0.46	1.35	-0.08	-0.47	-0.08	-0.62			-0.08	-0.46	-0.40	-0.88
	α_2	0.94	1.56	0.56	0.85	1.09	1.59	1.07	1.67			1.03	1.61	1.32	1.77
VEC	c	-0.18	-0.30	-0.28	-0.48	-0.18	-0.30	-0.19	-0.31	0.60	0.79			-0.16	-0.26
	α_1	0.00	0.00	0.59	1.87	0.04	0.28	-0.01	-0.07	1.03	1.61			0.08	0.19
	α_2	0.01	0.04	0.01	0.09	0.00	0.01	0.01	0.05	-0.08	-0.46			-0.01	-0.03
COMB	c	-0.17	-0.32	-0.27	-0.51	-0.19	-0.34	-0.25	-0.45	0.66	0.94	-0.16	-0.26		
	α_1	0.00	0.00	0.65	1.93	0.07	0.24	-0.16	-0.53	1.32	1.77	-0.01	-0.03		
	α_2	0.07	0.19	-0.20	-0.51	-0.10	-0.12	0.49	0.56	-0.40	-0.88	0.08	0.19		

4-quarter-ahead

m2 \ m1		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			-0.28	-0.25	0.25	0.23	-1.14	-1.19	2.08	1.24	-1.62	-1.20	0.08	0.08
	α_1			0.14	0.58	-0.35	-0.98	-0.79	-4.12	0.75	1.62	0.45	1.78	1.60	2.16
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	-0.28	-0.25			0.22	0.17	-0.97	-0.96	2.53	1.52	-2.44	-1.61	-0.23	-0.22
	α_1	0.00	0.00			-0.34	-0.77	-0.82	-4.08	1.16	2.22	0.54	2.06	1.66	2.23
	α_2	0.14	0.58			0.01	0.05	-0.13	-0.60	0.42	1.61	0.29	1.19	0.19	0.82
MSAR	c	0.25	0.23	0.22	0.17			-1.36	-1.30	3.57	1.94	-1.70	-1.28	1.06	1.03
	α_1	0.00	0.00	0.01	0.05			-0.83	-3.98	1.08	2.20	0.63	2.38	2.77	3.36
	α_2	-0.35	-0.98	-0.34	-0.77			0.19	0.54	-0.66	-1.77	-0.69	-1.85	-1.05	-2.69
MSVEC	c	-1.14	-1.19	-0.97	-0.96	-1.36	-1.30			0.95	0.64	-2.80	-2.31	-1.27	-1.54
	α_1	0.00	0.00	-0.13	-0.60	0.19	0.54			0.73	1.81	0.47	2.13	2.75	4.52
	α_2	-0.79	-4.12	-0.82	-4.08	-0.83	-3.98			-0.78	-4.19	-0.80	-4.29	-1.04	-5.98
ESTAR	c	2.08	1.24	2.53	1.52	3.57	1.94	0.95	0.64			-0.29	-0.09	1.15	0.66
	α_1	0.00	0.00	0.42	1.61	-0.66	-1.77	-0.78	-4.19			0.32	0.84	1.32	1.59
	α_2	0.75	1.62	1.16	2.22	1.08	2.20	0.73	1.81			0.31	0.45	0.39	0.76
VEC	c	-1.62	-1.20	-2.44	-1.61	-1.70	-1.28	-2.80	-2.31	-0.29	-0.09			-0.56	-0.36
	α_1	0.00	0.00	0.29	1.19	-0.69	-1.85	-0.80	-4.29	0.31	0.45			1.26	1.31
	α_2	0.45	1.78	0.54	2.06	0.63	2.38	0.47	2.13	0.32	0.84			0.17	0.54
COMB	c	0.08	0.08	-0.23	-0.22	1.06	1.03	-1.27	-1.54	1.15	0.66	-0.56	-0.36		
	α_1	0.00	0.00	0.19	0.82	-1.05	-2.69	-1.04	-5.98	0.39	0.76	0.17	0.54		
	α_2	1.60	2.16	1.66	2.23	2.77	3.36	2.75	4.52	1.32	1.59	1.26	1.31		

8-quarter-ahead

m2 \ m1		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			-1.68	-0.91	-2.10	-1.83	-1.00	-0.82	11.29	5.12	-9.63	-6.74	-1.85	-2.55
	α_1			0.58	1.69	1.06	7.56	1.01	6.44	2.09	6.19	1.84	9.27	2.00	14.52
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	-1.68	-0.91			-1.95	-1.48	-1.04	-0.73	9.67	4.40	-10.1	-6.78	-1.53	-1.82
	α_1	0.00	0.00			1.07	7.11	1.01	5.99	2.12	6.59	1.80	8.95	2.03	14.00
	α_2	0.58	1.69			-0.06	-0.24	0.02	0.06	0.64	2.50	0.24	1.08	-0.13	-0.77
MSAR	c	-2.10	-1.83	-1.95	-1.48			-2.40	-1.98	5.40	2.68	-8.26	-7.32	-1.62	-2.24
	α_1	0.00	0.00	-0.06	-0.24			-0.36	-0.76	1.29	4.27	1.33	7.61	2.43	8.88
	α_2	1.06	7.56	1.07	7.11			1.39	3.03	0.79	5.71	0.65	5.93	-0.32	-1.80
MSVEC	c	-1.00	-0.82	-1.04	-0.73	-2.40	-1.98			7.47	3.95	-8.39	-7.92	-1.92	-2.74
	α_1	0.00	0.00	0.02	0.06	1.39	3.03			1.52	5.24	1.48	9.59	2.44	10.28
	α_2	1.01	6.44	1.01	5.99	-0.36	-0.76			0.75	5.49	0.68	6.77	-0.36	-2.23
ESTAR	c	11.29	5.12	9.67	4.40	5.40	2.68	7.47	3.95			-6.62	-1.72	1.39	0.90
	α_1	0.00	0.00	0.64	2.50	0.79	5.71	0.75	5.49			1.64	5.27	1.76	10.61
	α_2	2.09	6.19	2.12	6.59	1.29	4.27	1.52	5.24			0.36	0.85	0.56	2.34
VEC	c	-9.63	-6.74	-10.1	-6.78	-8.26	-7.32	-8.39	-7.92	-6.62	-1.72			-5.42	-5.50
	α_1	0.00	0.00	0.24	1.08	0.65	5.93	0.68	6.77	0.36	0.85			1.49	9.30
	α_2	1.84	9.27	1.80	8.95	1.33	7.61	1.48	9.59	1.64	5.27			0.77	4.63
COMB	c	-1.85	-2.55	-1.53	-1.82	-1.62	-2.24	-1.92	-2.74	1.39	0.90	-5.42	-5.50		
	α_1	0.00	0.00	-0.13	-0.77	-0.32	-1.80	-0.36	-2.23	0.56	2.34	0.77	4.63		
	α_2	2.00	14.52	2.03	14.00	2.43	8.88	2.44	10.28	1.76	10.61	1.49	9.30		

For Peer Review

Table 8: Dollar/Yen – Fair and Shiller encompassing test

1-quarter-ahead

m1 / m2		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			-0.54	-0.81	-0.37	-0.55	-0.36	-0.52	-0.86	-1.33	-0.30	-0.45	-0.28	-0.42
	α_1			0.37	1.10	0.30	2.05	0.22	1.51	0.76	2.46	0.43	2.13	0.74	2.41
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	-0.54	-0.81			-0.36	-0.54	-0.36	-0.52	-0.98	-1.45	-0.30	-0.44	-0.25	-0.38
	α_1	0.00	0.00			0.27	1.74	0.18	1.12	0.95	2.27	0.41	1.80	0.93	2.21
	α_2	0.37	1.10			0.13	0.35	0.18	0.47	-0.30	-0.68	0.09	0.25	-0.30	-0.67
MSAR	c	-0.37	-0.55	-0.36	-0.54			-0.50	-0.73	-0.64	-0.96	-0.17	-0.25	-0.28	-0.42
	α_1	0.00	0.00	0.13	0.35			-0.32	-0.90	0.61	1.86	0.35	1.65	0.73	1.21
	α_2	0.30	2.05	0.27	1.74			0.60	1.63	0.20	1.32	0.23	1.56	0.00	0.01
MSVEC	c	-0.36	-0.52	-0.36	-0.52	-0.50	-0.73			-0.72	-1.04	-0.20	-0.29	-0.42	-0.64
	α_1	0.00	0.00	0.18	0.47	0.60	1.63			0.68	1.99	0.37	1.67	1.74	2.40
	α_2	0.22	1.51	0.18	1.12	-0.32	-0.90			0.09	0.62	0.12	0.82	-0.49	-1.52
ESTAR	c	-0.86	-1.33	-0.98	-1.45	-0.64	-0.96	-0.72	-1.04			-0.62	-0.90	-0.57	-0.81
	α_1	0.00	0.00	-0.30	-0.68	0.20	1.32	0.09	0.62			0.24	0.99	0.43	1.05
	α_2	0.76	2.46	0.95	2.27	0.61	1.86	0.68	1.99			0.57	1.55	0.47	1.15
VEC	c	-0.30	-0.45	-0.30	-0.44	-0.17	-0.25	-0.20	-0.29	-0.62	-0.90			-0.21	-0.32
	α_1	0.00	0.00	0.09	0.25	0.23	1.56	0.12	0.82	0.57	1.55			0.54	1.36
	α_2	0.43	2.13	0.41	1.80	0.35	1.65	0.37	1.67	0.24	0.99			0.21	0.82
COMB	c	-0.28	-0.42	-0.25	-0.38	-0.28	-0.42	-0.42	-0.64	-0.57	-0.81	-0.21	-0.32		
	α_1	0.00	0.00	-0.30	-0.67	0.00	0.01	-0.49	-1.52	0.47	1.15	0.21	0.82		
	α_2	0.74	2.41	0.93	2.21	0.73	1.21	1.74	2.40	0.43	1.05	0.54	1.36		

4-quarter-ahead

m1 / m2		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			-2.09	-1.49	-1.79	-1.02	-2.52	-1.28	-5.12	-3.11	1.63	0.89	0.82	0.52
	α_1			-0.15	-0.72	0.04	0.15	-0.13	-0.41	0.82	3.09	0.80	2.82	1.60	3.11
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	-2.09	-1.49			-2.15	-1.17	-3.01	-1.46	-5.61	-3.29	1.87	0.95	0.73	0.45
	α_1	0.00	0.00			-0.01	-0.05	-0.20	-0.61	1.01	3.20	0.84	2.71	1.58	3.00
	α_2	-0.15	-0.72			-0.15	-0.70	-0.18	-0.85	0.25	1.10	0.07	0.34	-0.05	-0.28
MSAR	c	-1.79	-1.02	-2.15	-1.17			-2.67	-1.35	-5.94	-2.83	1.17	0.60	-0.21	-0.13
	α_1	0.00	0.00	-0.15	-0.70			-0.56	-0.97	0.87	3.14	0.86	2.88	2.11	3.58
	α_2	0.04	0.15	-0.01	-0.05			0.45	0.89	-0.17	-0.64	-0.18	-0.68	-0.48	-1.69
MSVEC	c	-2.52	-1.28	-3.01	-1.46	-2.67	-1.35			-7.32	-3.18	0.14	0.07	-1.87	-1.10
	α_1	0.00	0.00	-0.18	-0.85	0.45	0.89			0.93	3.37	1.02	3.34	2.70	4.53
	α_2	-0.13	-0.41	-0.20	-0.61	-0.56	-0.97			-0.41	-1.36	-0.56	-1.76	-1.04	-3.08
ESTAR	c	-5.12	-3.11	-5.61	-3.29	-5.94	-2.83	-7.32	-3.18			-2.09	-0.78	-2.17	-0.88
	α_1	0.00	0.00	0.25	1.10	-0.17	-0.64	-0.41	-1.36			0.47	1.44	1.01	1.60
	α_2	0.82	3.09	1.01	3.20	0.87	3.14	0.93	3.37			0.59	1.88	0.51	1.56
VEC	c	1.63	0.89	1.87	0.95	1.17	0.60	0.14	0.07	-2.09	-0.78			1.66	0.92
	α_1	0.00	0.00	0.07	0.34	-0.18	-0.68	-0.56	-1.76	0.59	1.88			1.12	1.56
	α_2	0.80	2.82	0.84	2.71	0.86	2.88	1.02	3.34	0.47	1.44			0.37	0.95
COMB	c	0.82	0.52	0.73	0.45	-0.21	-0.13	-1.87	-1.10	-2.17	-0.88	1.66	0.92		
	α_1	0.00	0.00	-0.05	-0.28	-0.48	-1.69	-1.04	-3.08	0.51	1.56	0.37	0.95		
	α_2	1.60	3.11	1.58	3.00	2.11	3.58	2.70	4.53	1.01	1.60	1.12	1.56		

8-quarter-ahead

m1 / m2		RW		SP		MSAR		MSVEC		ESTAR		VEC		COMB	
		Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta	Coeff	Tsta
RW	c			-3.25	-1.39	1.49	0.85	3.14	1.78	-15.9	-5.16	2.58	0.61	1.99	1.66
	α_1			0.12	0.42	1.09	7.16	1.14	7.76	1.46	5.07	0.70	1.67	1.95	12.76
	α_2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	c	-3.25	-1.39			1.92	1.07	3.35	1.85	-16.1	-5.29	3.49	0.79	2.15	1.75
	α_1	0.00	0.00			1.11	7.23	1.14	7.71	1.55	5.38	0.76	1.78	1.95	12.68
	α_2	0.12	0.42			0.21	1.07	0.12	0.62	0.37	1.62	0.21	0.75	0.09	0.66
MSAR	c	1.49	0.85	1.92	1.07			3.10	1.66	-6.94	-2.41	2.67	0.86	1.72	1.42
	α_1	0.00	0.00	0.21	1.07			1.11	2.09	0.87	3.52	0.15	0.47	2.27	7.59
	α_2	1.09	7.16	1.11	7.23			0.03	0.06	0.87	5.76	1.08	6.74	-0.25	-1.23
MSVEC	c	3.14	1.78	3.35	1.85	3.10	1.66			-5.45	-1.95	3.42	1.15	1.57	1.21
	α_1	0.00	0.00	0.12	0.62	0.03	0.06			0.86	3.73	0.04	0.12	2.19	6.89
	α_2	1.14	7.76	1.14	7.71	1.11	2.09			0.93	6.53	1.14	7.31	-0.18	-0.84
ESTAR	c	-15.9	-5.16	-16.1	-5.29	-6.94	-2.41	-5.45	-1.95			-14.4	-2.81	0.92	0.36
	α_1	0.00	0.00	0.37	1.62	0.87	5.76	0.93	6.53			0.14	0.37	1.90	9.48
	α_2	1.46	5.07	1.55	5.38	0.87	3.52	0.86	3.73			1.42	4.64	0.11	0.47
VEC	c	2.58	0.61	3.49	0.79	2.67	0.86	3.42	1.15	-14.4	-2.81			-2.11	-1.02
	α_1	0.00	0.00	0.21	0.75	1.08	6.74	1.14	7.31	1.42	4.64			2.12	13.08
	α_2	0.70	1.67	0.76	1.78	0.15	0.47	0.04	0.12	0.14	0.37			-0.53	-2.37
COMB	c	1.99	1.66	2.15	1.75	1.72	1.42	1.57	1.21	0.92	0.36	-2.11	-1.02		
	α_1	0.00	0.00	0.09	0.66	-0.25	-1.23	-0.18	-0.84	0.11	0.47	-0.53	-2.37		
	α_2	1.95	12.76	1.95	12.68	2.27	7.59	2.19	6.89	1.90	9.48	2.12	13.08		

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4.3 Direction-of-change Measure of Forecast Accuracy

The third metric we use to evaluate forecast performance is the Percentage of Correct Direction Forecasts.

In exchange rate markets it is very insightful to know whether a specific forecast series generally co-moves with the actual exchange rate. In practice, *sign* forecast ability corresponds to evaluating whether the first differences in two series are the same.

For a given exchange rate model, we define Δ^{e}_{t+j} and Δ_{t+j} as the predicted and actual direction of change in exchange rate j periods ahead, respectively. These two variables evolve as follows:

$$\Delta^{e}_{t+j} = \begin{cases} 1 \text{ if } E_t e_{t+j} > e_t \\ -1 \text{ otherwise} \end{cases}$$

$$J = 1, 4, 8$$

$$\Delta_{t+j} = \begin{cases} 1 \text{ if } e_{t+j} > e_{t+j} \\ -1 \text{ otherwise} \end{cases}$$

Having calculated the two series, we can measure the performance of the forecast models in terms of correct directional change (CDC):

[18] $$CDC = \frac{1}{T}\sum_{t=1}^{T} \Phi\left\{\Delta^{e}_{t+j} = \Delta_{t+j}\right\}$$

where Φ takes the value 1 when its argument is true (that is, $\Delta^{e}_{t+j} = \Delta_{t+j}$), and 0 otherwise.

Table 9 reports the proportions of forecasts that correctly predict the actual directions of the dollar-euro, dollar-pound and dollar-yen. If a model has a CDC greater than 50% this means that it performs better than a random toss of a coin. The results suggest that in most cases the number of times the direction of change of both the actual and forecasted series agrees is greater than what would be expected by chance. Combined models outperform the other models over all forecasting horizons. ESTAR models are the second top performing models over both 1 and 4 quarters-ahead. At 8-step-ahead, with the exception of the COMB, MS-VECM models collect a higher number of agreements than the other five competitors. In general, non-linear models generate more accurate forecasts in terms of direction-of-change than their linear competitors.

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Table 9: Percentage of quarters where forecasts detect the correct direction of change

	Euro	*Rank*	Pound	*Rank*	Yen	*Rank*	*Avg. Rank*
1-quarter-ahead							
RW	64.02%	*[5]*	50.90%	*[7]*	64.02%	*[5]*	*[5.7]*
SP	59.10%	*[7]*	59.10%	*[4]*	65.66%	*[4]*	*[5.0]*
MS(2)-AR(4)	62.38%	*[6]*	67.30%	*[1]*	60.74%	*[7]*	*[4.7]*
VEC(4)	64.02%	*[4]*	52.54%	*[6]*	70.57%	*[1]*	*[3.7]*
MS(3)-VEC(4)	67.30%	*[2]*	59.10%	*[3]*	60.74%	*[6]*	*[3.7]*
ESTAR	65.66%	*[3]*	52.54%	*[5]*	67.30%	*[2]*	*[3.3]*
Comb(1-6)	70.57%	*[1]*	59.10%	*[2]*	65.66%	*[3]*	*[2.0]*
4-quarter-ahead							
RW	48.10%	*[7]*	58.45%	*[4]*	61.90%	*[5]*	*[5.3]*
SP	55.00%	*[1]*	49.83%	*[7]*	49.83%	*[7]*	*[5.0]*
MS(2)-AR(4)	49.83%	*[5]*	53.28%	*[6]*	73.97%	*[1]*	*[4.0]*
VEC(4)	51.55%	*[3]*	58.45%	*[3]*	58.45%	*[6]*	*[4.0]*
MS(3)-VEC(4)	51.55%	*[4]*	56.72%	*[5]*	67.07%	*[4]*	*[4.3]*
ESTAR	48.10%	*[6]*	61.90%	*[1]*	70.52%	*[2]*	*[3.0]*
Comb(1-6)	53.28%	*[2]*	59.39%	*[2]*	68.79%	*[3]*	*[2.3]*
8-quarter-ahead							
RW	53.15%	*[2]*	64.26%	*[1]*	53.15%	*[7]*	*[3.3]*
SP	51.30%	*[5]*	58.70%	*[5]*	58.70%	*[4]*	*[4.7]*
MS(2)-AR(4)	49.44%	*[7]*	51.30%	*[7]*	58.70%	*[3]*	*[5.7]*
VEC(4)	49.44%	*[6]*	53.15%	*[6]*	56.85%	*[5]*	*[5.7]*
MS(3)-VEC(4)	51.30%	*[4]*	63.00%	*[3]*	64.26%	*[1]*	*[2.7]*
ESTAR	56.85%	*[1]*	60.56%	*[4]*	53.15%	*[6]*	*[3.7]*
Comb(1-6)	51.30%	*[3]*	63.18%	*[2]*	55.91%	*[2]*	*[2.3]*

5. Conclusions

This paper analyzed the out-of-sample forecasting performance of a set of competing models of exchange rate determination. The literature on currency forecasting has developed different quantitative frameworks to model the exchange rate process without, however, producing a consensus view of the ability of alternative models to forecast the exchange rate in the short-run.

In the empirical part of the paper we estimated, forecasted and compared different models thought to capture the dynamics of the exchange rates. The econometric evidence resulting from this kind of study can suggest which model should be adopted in order to achieve a better forecasting performance.

A set of forecast evaluation techniques was employed to judge the relative performance of seven competing models. The forecasting models include linear models (such as RW and VECM), non-linear models (such as MS-AR, MS-VECM and

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ESTAR) and frequency-domain models based on spectral analysis (SP). We also proposed a forecasting method based on a weighted combination of individual forecast models.

In general, the results suggest that the behaviour of the exchange rate is episodically unstable. This reflects the significant sub-sample instability of alternative forecasting performances. We found that the switching nature of the exchange rate process is inconsistent with a linear representation over the whole sample period.. Non-linear models characterize the exchange rate behaviour so that that even if its dynamics is time-varying, it is possible to identify periods of time where its behaviour becomes stable.

We considered three classes of statistical measures - point forecast evaluation, forecast encompassing and directional accuracy. The evidence emerging from the point forecast evaluation corroborates the hypothesis of having more than one state operating during the sample period. In particular, the results suggest that forecasting performance varies significantly across currencies, across forecast horizons and across sub-samples. In general, our results suggest that combining forecasts from many models yields more accurate forecasts than utilizing the forecast of a single model. However, in most cases linear models outperform at short forecast horizons when deviations from long-term equilibrium are small. In contrast, nonlinear models with more elaborate mean-reverting components dominate at longer horizons especially when deviations from long-term equilibrium are large.

We also examined the predictive power of the various models by using the Fair and Schiller encompassing tests. These tests confirm that combined forecasts encompass the competing models for three selected currencies. Moreover, the results indicate that mean-reversion models outperform random walks. Out-of-sample forecast from non-linear models encompass naïve constant-change forecasts.

Finally, direction-of-change measures of forecast accuracy suggest that combining different frameworks for forecasting exchange rates generate more accurate forecasts in terms of sign forecastability. Again, the results suggest that combining the individual forecasts achieve, on average, the best performance among all the competing forecasts.

Overall, the empirical results suggest that the relative success of competing models of exchange rate forecasting mostly depend on the distance between the exchange rate

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and its fundamentals., i.e. when this distance is not too large, linear models better approximate the exchange rate behaviour. In the limit, when exchange rates and their fundamentals coincide, the best forecasting model turns out to be the naïve random walk. In contrast, non-linear models significantly improve the forecast accuracy when the exchange rate deviates substantially from its fundamental. This means that *ex-ante* the degree of non-linearity a forecaster should take into account in determining the future movements of exchange rate depends on how large he judges the difference between exchange rate and fundamentals to be.

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